chapter 15

Endocrine System

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Olga Yegorova upset reigning 5000 m champion Gabriela Szabo at the 2001 World Track and Field Championships held in Edmonton. The usually polite Canadian audience booed Yegorova as she crossed the finish line. The Russian distance runner was booed for what was perceived to be an unfair advantage—taking the banned chemical hormone, erythropoietin (EPO). Following a competition in Paris, Yegorova had tested positive for erythropoietin, but she had been reinstated just before the world championships on a technicality. Although EPO was detected in Yegorova's urine, the Paris track meet organizers failed to do the required follow-up blood test. By the time Yegorova was tested again, abnormally high levels of EPO could no longer be identified.

Erythropoietin is a naturally occurring hormone produced by the kidneys. It boosts red blood cell production, increasing oxygen transport to the tissues. More oxygen means greater energy for endurance athletes. Tests have shown that athletic enhancement gained by using EPO for four weeks matches that of several years of training. But EPO is dangerous. Increased red blood cell production makes the blood thicker and more difficult to pump. Very high red blood cell counts can increase blood clotting and overwork the heart. According to some doping experts, the deaths of 20 European cyclists between 1988 and 1998 can be linked directly to EPO use.

Since the body produces EPO, it is difficult to detect. New tests that analyze blood for abnormally high red blood cell volume and analyze for unusually high EPO levels are being used to detect its use. Unfortunately, athletes can still avoid getting caught by stopping EPO treatments a few weeks before the tests.

STARTING Points

Answer these questions as best you can with your current knowledge. Then, using the concepts and skills you have learned, you will revise your answers at the end of the chapter.

1. Explain how hormones help the body adjust to stress.
2. Antidiuretic hormone (ADH) and aldosterone are hormones that affect the kidney. Explain why the regulatory systems for osmotic pressure of fluids and for body fluid volumes are controlled by chemicals carried by blood, rather than by nerves.

Career Connections:
Licensed Practical Nurse; Pharmacist

Figure 1
Gabriela Szabo of Romania leads Olga Yegorova in a race.

Exploration — Chemical Signals and Sports

Find out more about the use of banned drugs in sports.

(a) Choose one banned drug and explain the unfair advantage it provides.
(b) What are some of the health risks associated with its use?
(c) Identify some of the technologies used to detect whether an athlete is using the drug.

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15.1 Homeostasis, Hormones, and the Endocrine System

The human body works best at a temperature of 37 °C, with a 0.1 % blood glucose level and a blood pH of 7.35. However, the external environment does not always provide the ideal conditions for life. Air temperatures in Canada can fluctuate between –40 °C and +40 °C. Rarely do foods consist of 0.1 % glucose and have a pH of 7.35. You also place different demands on your body when you take part in various activities, such as playing racquetball, swimming, or digesting a large meal. Your body systems must adjust to these variations to maintain a stable internal environment. **Homeostasis** refers to the body's attempt to adjust to a fluctuating environment. The body maintains a constant balance, or steady state, through a series of adjustments. This system of balance requires constant monitoring and feedback about body conditions (**Figure 1**). An increase in heart rate during exercise and the release of glucose from the liver to restore blood sugar levels are a couple of examples of the adjustments made. The concept of homeostasis is central to how the endocrine system operates.

homeostasis the process by which a constant internal environment is maintained despite changes in the environment

DID YOU KNOW?

Discovering Homeostasis

The word *homeostasis* was coined in 1932 when Walter Cannon, a physiology professor at Harvard University, published the book *Wisdom of the Body*. Aided by new X-ray equipment, Cannon was able to mix food with barium sulfate and follow it toward the stomach. He noted that the waves of contraction that pushed along the digestive tract could be suspended if the animal were frightened. Cannon surmised that higher mammals have a complex system of self-regulatory mechanisms that keep the body stable under various physical and emotional circumstances.

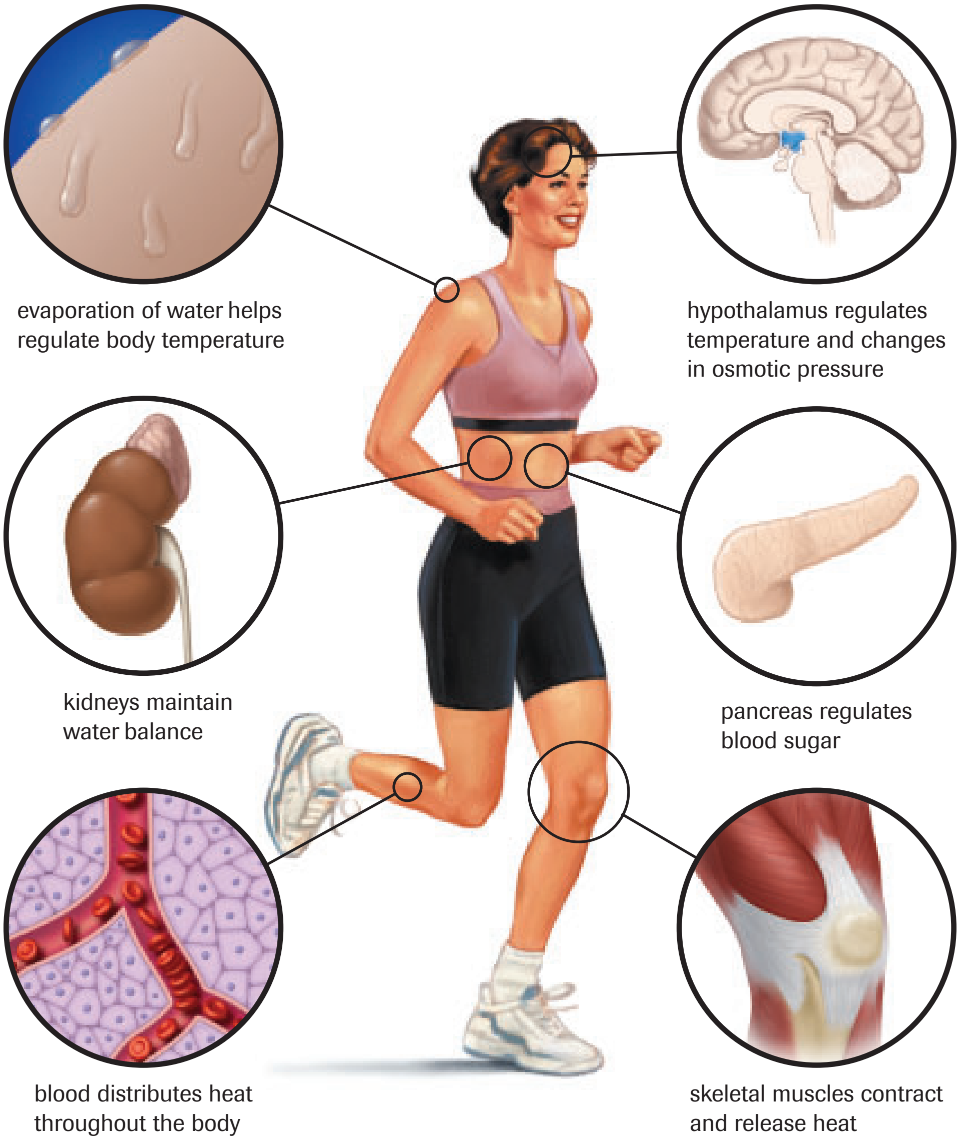

Figure 1
Homeostasis requires the interaction of several regulatory systems. Information about blood sugar, fluid balance, body temperature, oxygen levels, and blood pressure is relayed to a nerve coordinating centre. Once their levels move outside the normal limits, regulators bring about the needed adjustments.

All homeostatic control systems have three functional components: a receptor, a coordinating centre, and an effector (**Figure 2**). Special receptors located in the organs of the body signal a coordinating centre once an organ begins to operate outside its normal limits. The coordinating centre relays the information to the appropriate effector, which helps to restore the normal balance. For example, when carbon dioxide levels increase during exercise, chemical receptors in the brainstem are stimulated. Nerve cells from the brain then carry impulses to effector muscles, which increase the depth and rate of breathing. The increased breathing movements help flush excess carbon dioxide from the body.

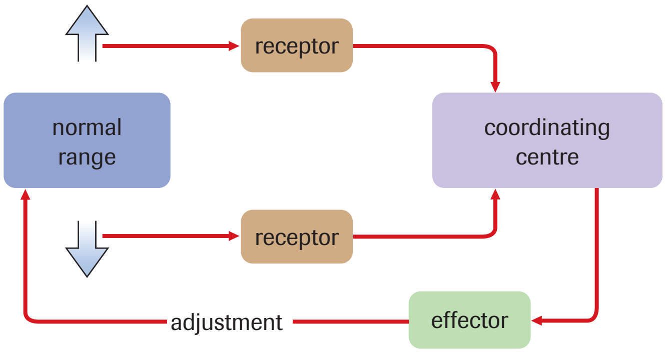

Figure 2
A schematic diagram of a control system

A group of chemical receptors in the arteries in the neck can detect low levels of oxygen in the blood. A nerve is excited and sends a message to the brain, which relays the information by way of another nerve to the muscles that control breathing movements. This system ensures that oxygen levels are maintained within an acceptable range. Homeostasis is often referred to as a **dynamic equilibrium**. Although there are fluctuations in blood glucose, body temperature, blood pressure, and blood pH, the homeostatic mechanism ensures that all body systems function within an acceptable range to sustain life (**Figure 3**).

dynamic equilibrium a state of stability within fluctuating limits

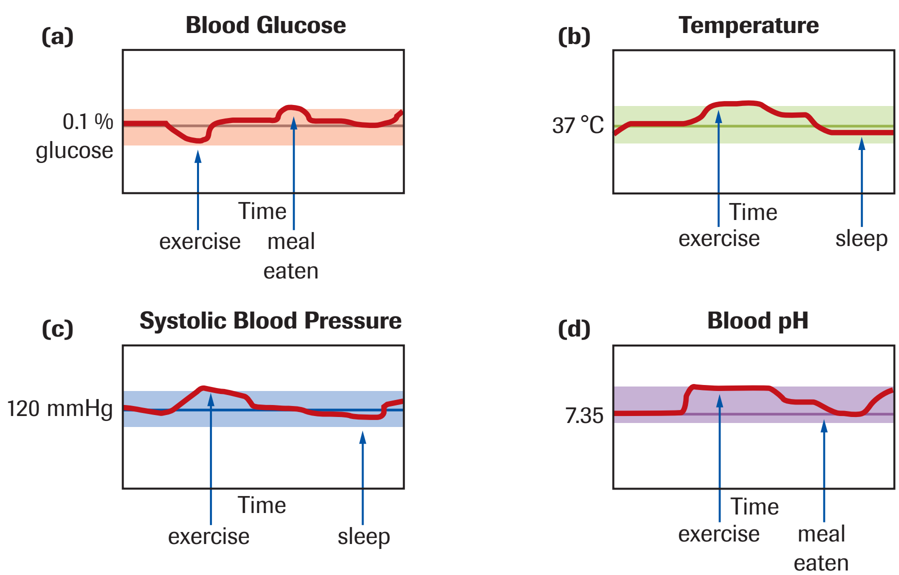

Figure 3
Blood glucose **(a)** is maintained within a narrow range and movement outside of the range can signal disease. Body temperature **(b)** can fluctuate by +2 °C with exercise and −2 °C with sleep. Systolic blood pressure **(c)** is usually near 120 mmHg but can move as high as 240 mmHg in a very fit athlete for a limited time during strenuous exercise. Blood pH **(d)** operates within a narrow range, and changes of ±0.2 can lead to death.

Homeostasis and Feedback Systems

negative feedback the process by which a mechanism is activated to restore conditions to their original state

Mechanisms that make adjustments to bring the body back within an acceptable range are referred to as **negative feedback** systems. The household thermostat is an example of such a system (**Figure 4**). In this case, the coordinating centre, called a thermostat, also contains the receptor (a thermometer). When the room temperature falls below a set point, say 20 °C, the thermostat switches on the effector (the furnace). When the thermometer detects a temperature above the set point, the thermostat switches off the furnace. This type of control circuit is called negative feedback because a change in the variable being monitored (e.g., temperature) triggers the control mechanism to counteract any further change in the same direction. Negative feedback mechanisms prevent small changes from becoming too large. Most homeostatic mechanisms in animals operate on this principle of negative feedback.

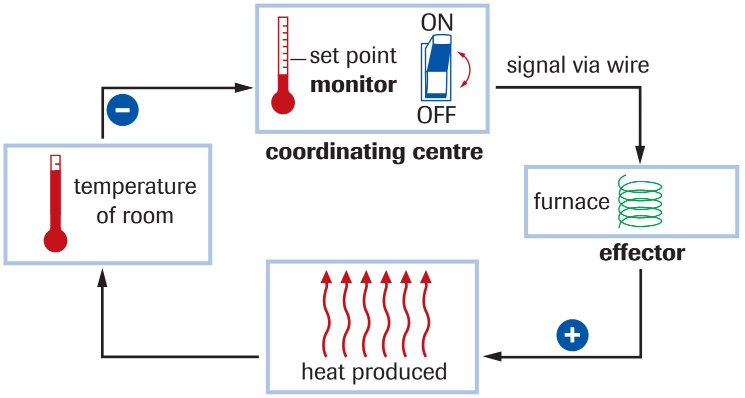

Figure 4
The household thermostat illustrates a negative feedback system. When the variable (temperature) exceeds the set point, the coordinating centre turns the effector off. The + indicates "stimulation" or "activation," and the − indicates "inhibition" or "turning off."

positive feedback the process by which a small effect is amplified

Positive feedback systems are less common in the body. Whereas negative feedback systems are designed to resist change, positive feedback systems reinforce change. Positive feedback systems move the controlled variable away from a steady state. The value of a positive feedback system is that it allows a discrete physiological event to be accomplished rapidly. Once this event is accomplished, the feedback system stops.

Practice

1. Define homeostasis.
2. Use the example of a thermostat to explain homeostasis.
3. Explain the negative feedback system shown in **Figure 5**.

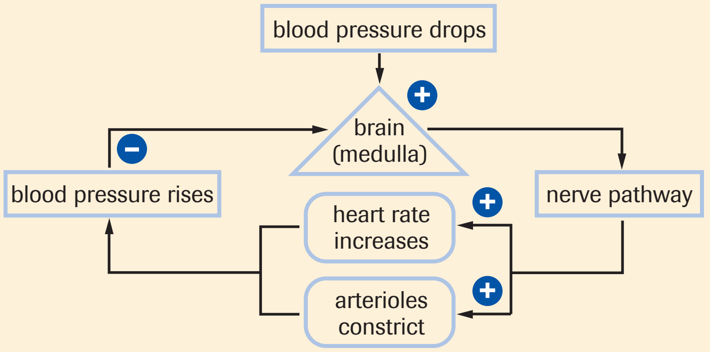

Figure 5

Hormones

The trillions of cells of the body all interact with each other—no cell operates in isolation. The integration of body functions depends on chemical controls. **Hormones** are chemical regulators produced by cells in one part of the body that affect cells in another part of the body. The word *hormone* comes from the Greek *hormon*, meaning "to excite or set into motion." Hormones serve as regulators, speeding up or slowing down certain bodily processes. Only a small amount of a hormone is required to alter cell metabolism. Chemicals produced by endocrine glands (**Figure 6**) and secreted directly into the blood are referred to as **endocrine hormones** (**Figure 7**). The circulatory system carries these hormones to the various organs of the body.

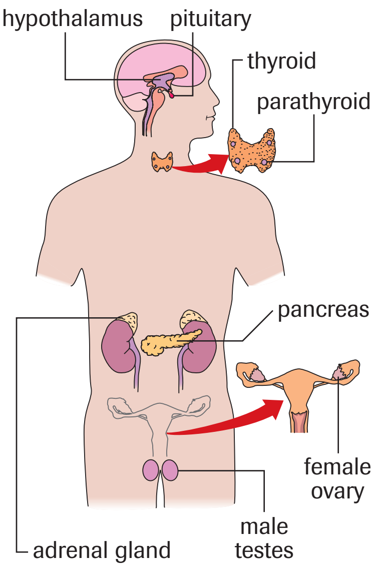

Figure 6
The location and appearance of some important endocrine glands in the human body. Hidden within the thyroid gland are four small glands—the parathyroid glands.

Figure 7
Endocrine hormones are chemical controls involved in the regulation of growth, development, and homeostasis. This sequence of photos is a computer simulation of the aging process based on statistical data.

Hormones can be classified according to their activation site. Some hormones are called nontarget hormones. They affect many cells or tissues throughout the body. For example, **insulin** makes practically all cells in the body permeable to glucose and makes liver cells to convert glucose to glycogen. **Human growth hormone (hGH)** and **epinephrine** are also non-target hormones. Other hormones affect specific cells or target tissues. For example, gastrin stimulates only certain stomach cells, which then produce digestive enzymes.

Chemical Control Systems

Along with the nervous system, the endocrine system provides integration and control of the organs and tissues to maintain homeostasis. The nervous system enables the body to adjust quickly to changes in the environment. The endocrine system is designed to maintain control over a longer duration. Hormones such as growth hormone and the various hormones involved in reproduction, for example, regulate and sustain development for many years.

The division between the nervous system and endocrine system is most subtle in the hypothalamus. The hypothalamus regulates the pituitary gland through nerve stimulation as well as by releasing hormones. However, the endocrine glands, stimulated by the pituitary, secrete chemicals that affect the nerve activity of the hypothalamus.

Hormones do not affect all cells. Cells may have receptors for one hormone, but not another. The number of receptors on individual cells may also vary. For example, liver cells and muscle cells have many receptor sites for the hormone insulin, but less active cells such as bone and cartilage cells have fewer receptors.

hormones chemicals released by cells that affect cells in other parts of the body

endocrine hormones chemicals secreted by endocrine glands directly into the blood

insulin hormone produced by the islets of Langerhans in the pancreas; insulin is secreted when blood sugar levels are high

human growth hormone (hGH) hormone produced by the pituitary gland that stimulates growth of the body; also known as somatotropin (STH)

epinephrine (adrenaline) hormone, produced in the adrenal medulla that accelerates heart rate and body reactions during a crisis (the fight-or-flight response)

Hormones may also be classified by their chemical nature. Most hormones are water-soluble, and are proteins, peptides, or amino acid derivatives. Water-soluble hormones act from outside the cell by binding to receptor sites on the cell membrane, which activates enzymes in the cytoplasm to carry out specific functions (**Figure 8 (a)**). The second class of hormones is fat-soluble hormones, which are also called steroids. Steroids act from inside the cell, by diffusing into a specific cell and binding with receptor molecules in the cytoplasm, which signals the cell to produce a specific protein (**Figure 8 (b)**). You will learn more about specific members of these two classes in the rest of this unit and in Unit 30 B.

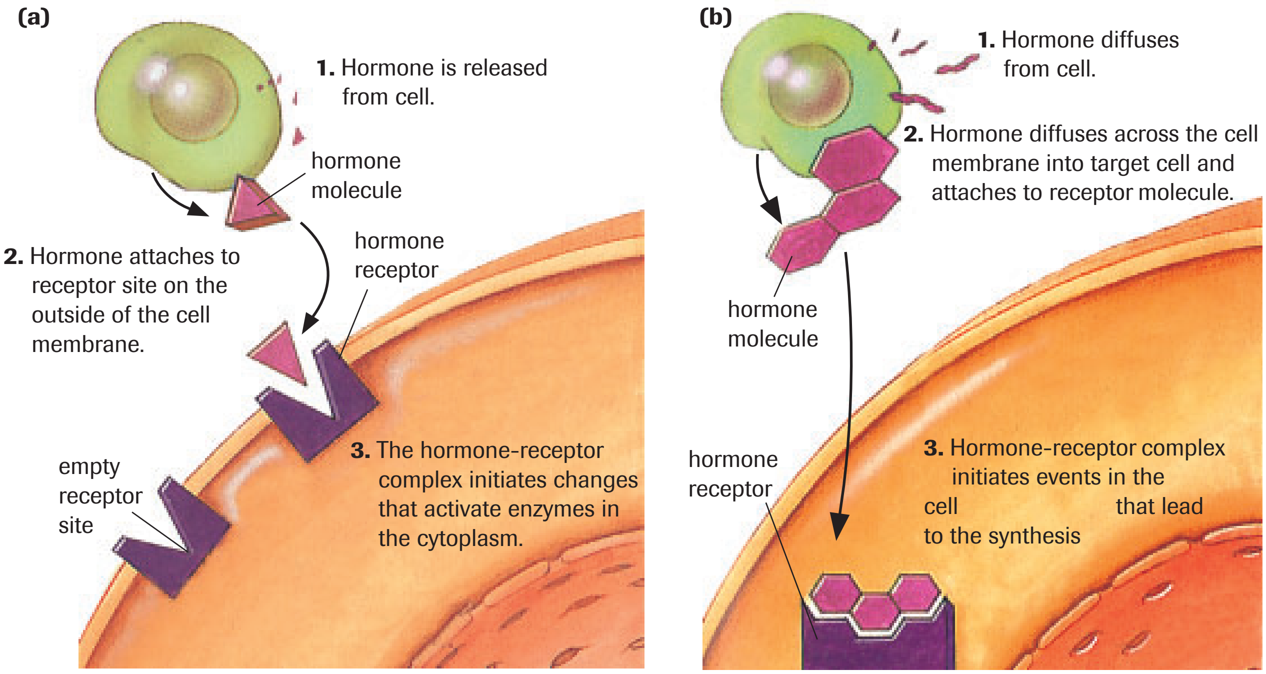

Figure 8
(a) A water-soluble hormone molecule combines with its receptor on the cell membrane. This triggers events in the cell that lead to the activation of enzymes in the cytoplasm.
(b) A fat-soluble (steroid) hormone molecule passes through the cell membrane of the target cell and combines with its receptor in the cytoplasm. This triggers events in the cell that lead to the production of a specific protein.

DID YOU KNOW?

Exocrine Glands

Exocrine glands, unlike the endocrine glands, are glands that secrete substances through ducts or tubes onto a body surface or into a cavity. Most of the body's glands are exocrine glands. Digestive, mucous, sebaceous, and sweat glands are included in this category. The pancreas is considered both an exocrine gland and an endocrine gland.

Regulating Hormones

Hormone production must be regulated. Once a hormone produces the desired effect, production of that hormone must be decreased to maintain normal body functioning.

Consider, for example, the hormone epinephrine (adrenaline). Epinephrine enables the body to respond to stressful situations. Among other responses, the hormone causes pulse and breathing rates to accelerate and blood sugar levels to rise. All actions are designed to allow the body to respond to stress in what has come to be known as the "flight-or-fight" response. However, once the stressful situation is gone, the body returns to normal resting levels. Once again, negative-feedback action is required to restore homeostasis. Throughout this chapter, you will study other specific examples of negative feedback.

Practice

4. Define an endocrine hormone.
5. Do hormones affect every cell in the body? Explain why or why not.
6. Explain why hormones must be regulated.

DID YOU KNOW?

Unused Protein Hormones

Protein hormones that do not attach to receptor molecules on target cells are removed from the body by the liver or kidney. The presence of these hormones can be monitored by urinalysis.

The Pituitary Gland: The Master Gland

The **pituitary gland** is often referred to as the "master gland," because it exercises control over other endocrine glands. This small, sac-like structure is connected by a stalk to the hypothalamus, the area of the brain associated with homeostasis. The interaction between the nervous system and endocrine system is evident in the hypothalamus–pituitary complex (**Figure 9**, next page). The pituitary gland produces and stores hormones. The hypothalamus stimulates the release of hormones by the pituitary gland by way of nerves and by releasing hormones.

Releasing hormones (also called releasing factors) are peptides that stimulate the pituitary to release a stored hormone.

The posterior lobe of the pituitary does not synthesize hormones. Instead, it stores and releases hormones that have been synthesized by the hypothalamus, such as antidiuretic hormone (ADH). You learned in Unit 20 D that this hormone acts on the kidneys and helps regulate body water. The ADH travels from the hypothalamus to the pituitary by way of specialized nerve cells (**Figure 9 (a)**, next page). Once at the posterior pituitary lobe, the ADH is stored until it is needed, at which time it is released into the blood.

In contrast, the anterior lobe of the pituitary synthesizes its own hormones. The secretion of the pituitary hormones by the posterior lobe, such as hGH (**Figure 9 (b)**, next page), is governed by factors secreted by the hypothalamus. Releasing factors stimulate the pituitary to secrete its hormones, and **inhibiting factors** stop pituitary secretions. These factors travel from the hypothalamus to the pituitary by a series of blood vessels.

Table 1 summarizes the hormones produced by the pituitary gland. Most of the pituitary hormones will be discussed in detail in the following sections.

pituitary gland gland at the base of the brain that, together with the hypothalamus, functions as a control centre, coordinating the endocrine and nervous systems

releasing hormone a peptide produced by the hypothalamus that stimulates the anterior pituitary gland to release a stored hormone; also called a releasing factor

inhibiting factor chemical that inhibits production of a hormone by the anterior pituitary gland

Table 1 Pituitary Hormones

Hormone	Target
Anterior lobe	
thyroid-stimulating hormone (TSH)	thyroid gland
adrenocorticotropic hormone (ACTH)	adrenal cortex
human growth hormone (hGH)	most cells
follicle-stimulating hormone (FSH)	ovaries, testes
luteinizing hormone (LH)	ovaries, testes
prolactin (PRL)	mammary glands
melanocyte-stimulating hormone (MSH)	melanocytes in skin
Posterior lobe	
oxytocin	uterus, mammary glands
antidiuretic hormone (ADH)	kidneys

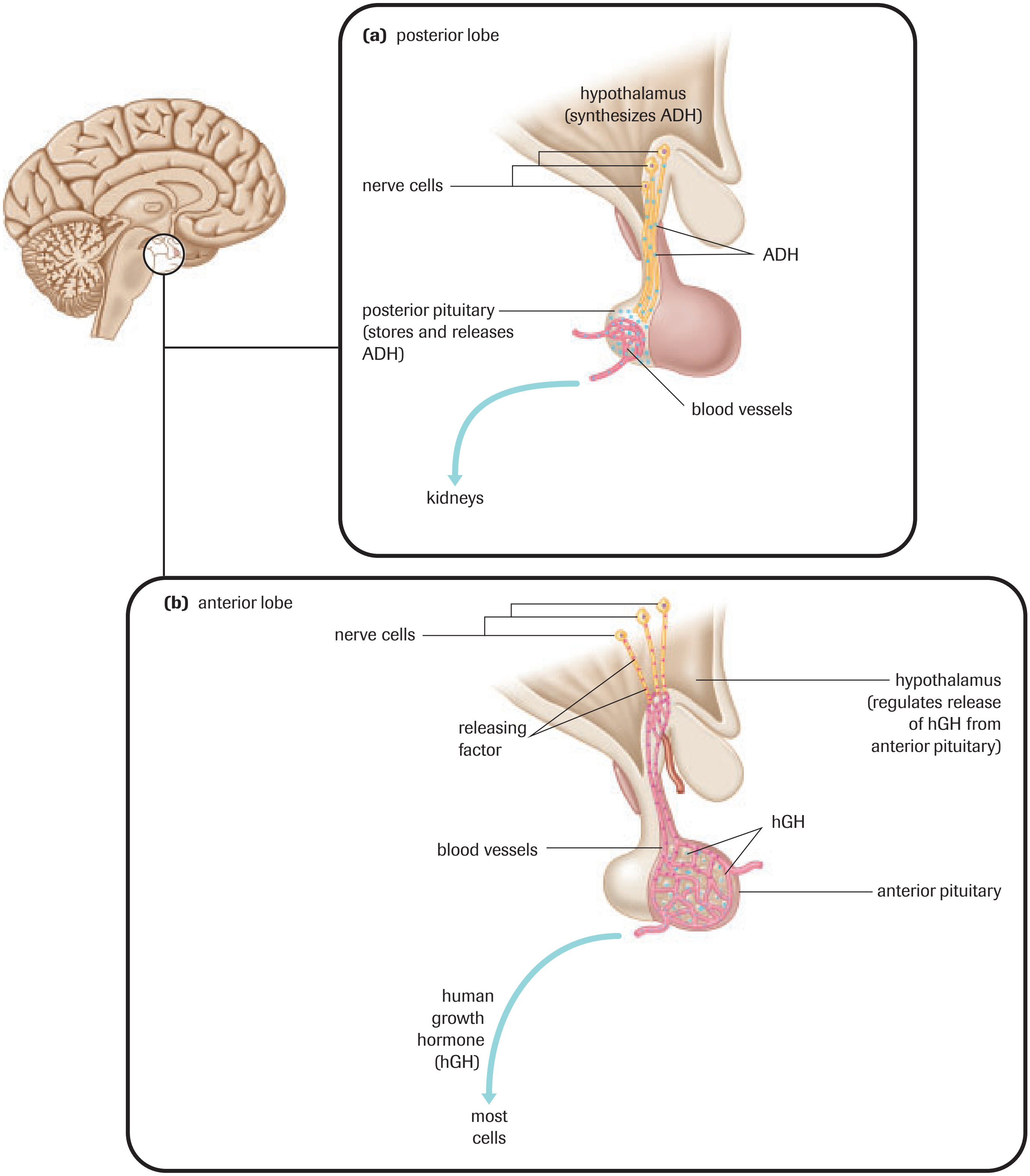

Figure 9
The pituitary gland is composed of two separate lobes: the posterior lobe and the anterior lobe.
(a) In this example, the cells of the hypothalamus synthesize antidiuretic hormone (ADH), which travels from the hypothalamus to the pituitary along specialized nerve cells. The ADH molecules remain in the pituitary gland and are released into the blood when they are needed.
(b) Releasing and inhibiting factors secreted by nerve cells of the hypothalamus travel along blood vessels to the anterior pituitary where they regulate the secretion of hormones such as hGH.

Using Recombinant DNA Technology to Produce Hormones

Genetic engineering involves extracting genes from human chromosomes and inserting them into bacteria, which then synthesize the human gene product. Recombinant DNA technology has been widely used by drug companies to produce human hormones.

Human growth hormone (hGH) can be produced by this technology. Normally produced by the pituitary, hGH primarily promotes the growth of bone and muscle. Lower than normal concentrations can cause dwarfism, extreme fatigue, anxiety, and malaise. One estimate indicates that 3 in 10 000 people have a serious deficiency of hGH.

Humans do not respond to animal growth hormone, and hGH has to be extracted from cadavers, of which there is a limited supply. Only a minute quantity of hGH can actually be extracted from the pituitary of a cadaver. In addition, the brain tissue from a cadaver might have been infected with a disease-causing agent such as the infectious protein that causes Creutzfeldt-Jacob disease, the human equivalent of mad cow disease. In 1985, recombinant DNA human growth hormone (rhGH) first became available.

Although rhGH provides a ready supply of hormone, its use has raised many ethical questions. Should rhGH be available only to children who have dwarfism or to any child that might want to be taller? Should dwarfism be treated as a disease, or viewed as one part of human diversity?

SUMMARY *Homeostasis, Hormones and the Endocrine System*

- Homeostasis is the body's attempt to keep all its systems operating within normal limits in a fluctuating environment.
- The endocrine system and nervous system work together to maintain homeostasis.
- All homeostatic control systems have three functional components: a receptor, a coordinating centre, and an effector.
- Negative feedback mechanisms trigger a response that reverses the changed condition; positive feedback mechanisms move the controlled variable even farther away from a steady state.
- The hypothalamus controls the production of pituitary hormones.

Section 15.1 Questions

1. Differentiate between positive and negative feedback systems.
2. Use **Figure 10** to explain homeostasis.

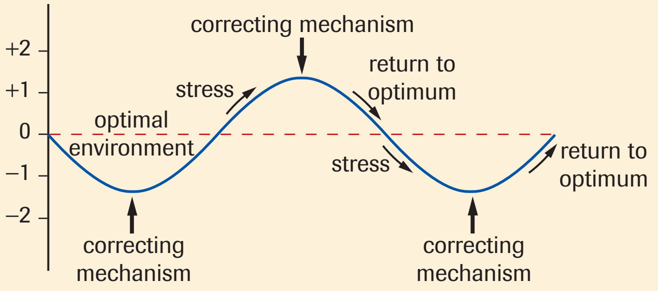

Figure 10

3. What are target tissues or organs?
4. Explain how the nervous system and endocrine system are specialized to maintain homeostasis.
5. Compare water-soluble and fat-soluble hormones.
6. Compare the anterior and posterior lobes of the pituitary. How are they similar and how are they different?
7. Some scientists have speculated that certain young female Olympic gymnasts may have been given growth hormone inhibitors. Why might the gymnasts have been given growth inhibitors? Do you think hormone levels should be altered to regulate growth patterns?
8. Compare the cells of the hypothalamus to cells of the pituitary.

15.2 Hormones That Affect Blood Sugar

islets of Langerhans hormone-producing cells of the pancreas; these cells are part of the endocrine system

glucagon hormone produced by the pancreas; when blood sugar levels are low, glucagon promotes conversion of glycogen to glucose

Two members of the endocrine system affect blood sugar levels in humans: specific cells in the pancreas and the adrenal glands. The pancreas contains two types of cells: one type that produces digestive enzymes and a second type that produces hormones. The hormone-producing cells are located in structures called the **islets of Langerhans**, named after their discoverer, German scientist Paul Langerhans. More than 200 000 tiny islets, each containing thousands of cells, are scattered throughout the pancreas. The islets contain beta and alpha cells that are responsible for the production of two hormones: insulin and **glucagon**.

Insulin is produced in the beta cells of the islets of Langerhans and is released when the blood sugar level increases. After a meal, the blood sugar level rises and an appropriate amount of insulin is released (**Figure 1**). The insulin causes cells of the muscles, the liver, and other organs to become permeable to the glucose. Also, in the liver, glucose is

EXTENSION

Hormones and Blood Glucose Regulation

In this Audio Clip, you can hear a discussion of how specific hormones work together to maintain blood glucose homeostasis.

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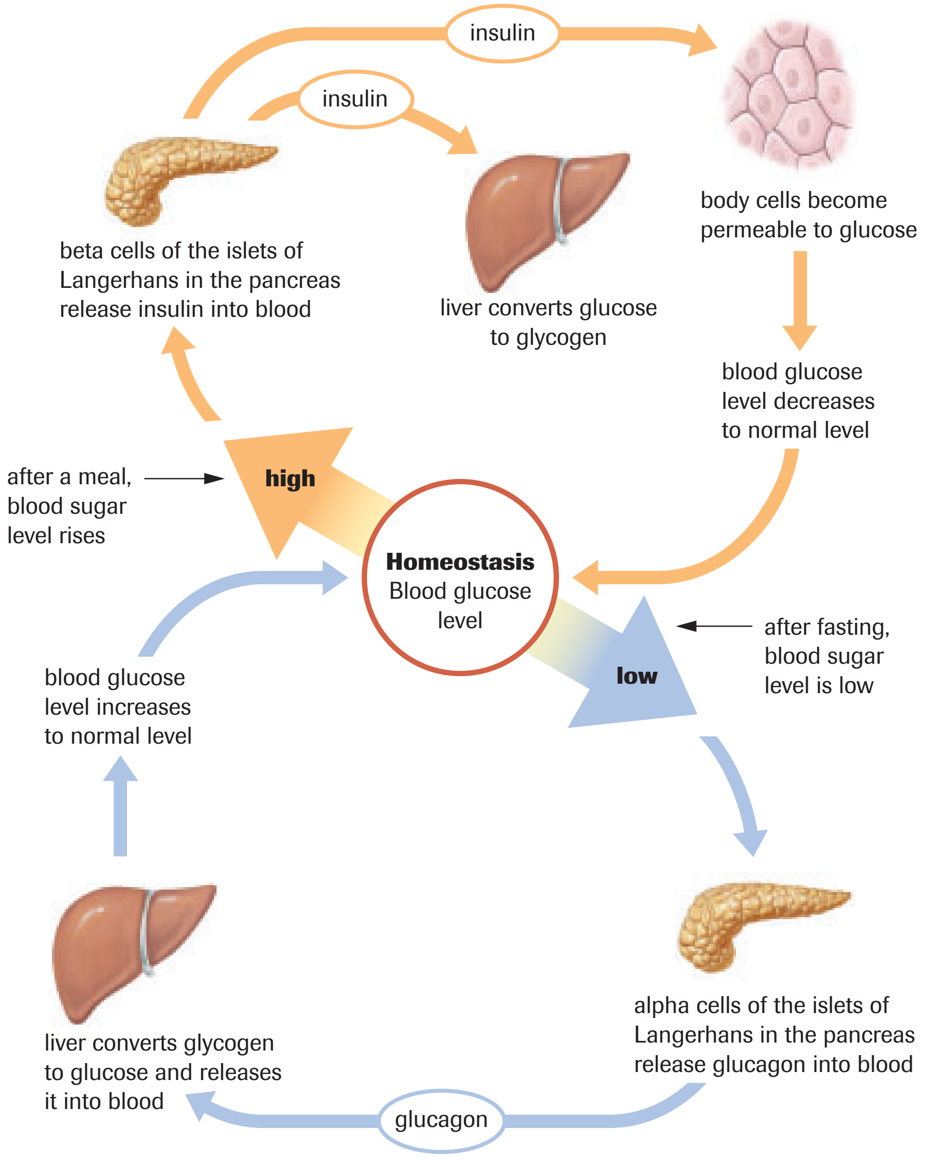

Figure 1
Insulin, released when blood sugar levels are high, increases the permeability of cells to glucose. Glucose is converted into glycogen within the liver, thereby restoring blood sugar levels. Glucagon, released when blood sugar levels are low, promotes the conversion of liver glycogen into glucose, thereby restoring blood sugar levels.

converted into glycogen, the primary storage form for glucose. This enables the blood sugar level to return to normal. In this way, insulin helps maintain homeostasis.

Glucagon and insulin work in a complementary fashion. Insulin causes a decrease in the blood sugar level, and glucagon causes an increase in the blood sugar level. Produced by the alpha cells of the islets of Langerhans, glucagon is released when blood sugar levels are low, such as after periods of fasting. Glucagon promotes the conversion of glycogen to glucose, which is released into the blood. As glycogen is converted to glucose in the liver, the blood sugar level returns to normal.

Diabetes

Diabetes is a chronic disease with no cure that affects more than two million Canadians. It is caused by insufficient production or use of insulin. When left untreated, it can cause blindness, kidney failure, nerve damage, and nontraumatic limb amputation.

diabetes chronic disease in which the body cannot produce any insulin or enough insulin, or is unable to use properly the insulin it does make

Without adequate levels of insulin, blood sugar levels rise very sharply following meals. This condition is known as hyperglycemia, or high blood sugar (from *hyper*, meaning "too much"; *glyco*, meaning "sugar"; and *emia* referring to a condition of the blood). The kidneys are unable to reabsorb all the blood glucose that is filtered through them, so the glucose appears in the urine. Since high concentrations of glucose in the nephrons draw water out of the plasma by osmosis, people with diabetes excrete unusually large volumes of urine and are often thirsty.

People with diabetes often feel tired. Remember that insulin causes cells to become permeable to glucose. Despite the abundance of glucose in the blood, little is able to move into the cells. The cells must turn to other sources of energy. Fats and proteins can be metabolized for energy, but, unlike carbohydrates, they are not an easily accessible energy source. The switch to these other energy sources creates a host of problems. Acetone, an intermediate product of excessive fat metabolism, can be produced. In severe cases, the smell of acetone can be detected on the breath of these people.

There are three main types of diabetes mellitus. Type 1 diabetes (formerly known as juvenile-onset diabetes) occurs when the pancreas is unable to produce insulin because of the early degeneration of the beta cells in the islets of Langerhans. It is usually diagnosed in childhood, and people who have it must take insulin to live (**Figure 2**). Approximately 10 % of people with diabetes have type 1 diabetes.

Type 2 diabetes (sometimes referred to as adult-onset diabetes) is associated with decreased insulin production or ineffective use of the insulin that the body does produce. It is usually diagnosed in adulthood and can be controlled with diet, exercise, and oral drugs known as sulfonamides (which are ineffective against type 1 diabetes). About 90 % of people with diabetes have type 2 diabetes.

A third type of diabetes, gestational diabetes, is a temporary condition that occurs in 2 % to 4 % of pregnancies. It increases the risk of type 2 diabetes in both mother and child.

DID YOU KNOW?

Hypoglycemia

When the blood sugar level falls below normal, a condition known as hypoglycemia occurs. Hypoglycemia can be caused by too much insulin or too little glucagon.

Figure 2
The pen is the newest way of injecting insulin. It is portable, accurate, and easy to use.

Practice

1. How does insulin regulate blood sugar levels?
2. How does glucagon regulate blood sugar levels?
3. Using a flow chart, show a homeostatic adjustment for a person who has consumed a significant amount of carbohydrates in the past hour.

INVESTIGATION 15.1 *Introduction*

Identification of Hyperglycemia

How is urinalysis used to identify diabetes? In this investigation, you will use simulated urine samples to identify diabetes.

Report Checklist

- ● Purpose
- ○ Problem
- ● Hypothesis
- ● Prediction
- ● Design
- ○ Materials
- ○ Procedure
- ● Evidence
- ● Analysis
- ● Evaluation
- ● Synthesis

To perform this investigation, turn to page 498.

Figure 3
Dr. Charles Best (left) and
Dr. Frederick Banting (right)

WWW WEB Activity

Canadian Achievers—Banting and Best

Working together at the University of Toronto, Dr. Frederick Banting and Dr. Charles Best (**Figure 3**) were able to isolate insulin and to then use the hormone as the first successful treatment of diabetes. Follow the links on the Nelson Web site to learn more about the remarkable work of these two scientists.

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CAREER CONNECTION

Licensed Practical Nurse

Licensed Practical Nurses provide health care in a variety of community care facilities such as schools, health units, nursing homes, and hospitals. Specialized training can be obtained and combined with clinical experience to further career advancement for these health care professionals.

Do you have a caring attitude with excellent communication and interpersonal skills? Above average employment turnover is expected in this career area!

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Islet Cell Transplants

Type 1 diabetes is the second leading cause of blindness in Canada. Other side effects of the disease, such as kidney and heart failure, stroke, and peripheral nerve damage, affect more than 50 000 Canadians. Although insulin injections provide some regulation of blood sugar, they do not necessarily prevent many of the serious complications of diabetes.

Transplanted islet cells, however, could replace the body's natural mechanism for monitoring and producing insulin. Unlike insulin therapy, islet cell transplantation holds the potential to reverse the effects of diabetes. One of the main barriers to successful clinical islet transplantation is immune rejection. Current anti-rejection drugs are toxic and harmful to islet function, and immunosuppression leaves the recipients susceptible to invading microbes.

Researchers around the world are searching for solutions. A team of researchers at the University of Alberta has pioneered a treatment—known as the Edmonton Protocol—designed by Dr. James Shapiro, director and head of the Clinical Islet Transplant Program (**Figure 4**, next page). The treatment uses a combination of three drugs to prevent rejection of the transplanted islets and to prevent diabetes from returning. The success of the treatment depends on new methods of isolating and transplanting pancreatic cells.

Unlike other types of transplant surgery, the technique used for islet transplants presents few risks. Islet cells are extracted from the pancreas of a donor and infused into the recipient's liver by way of a large vein. The surgeon uses ultrasound to see the vein leading into the liver, the skin is frozen, and a syringe is used to put the new cells in place. The patient can usually return home the next day. The liver is used because, when damaged, it is able to regenerate itself by building new blood vessels and cells. New blood vessels and nerve cells connect to the transplanted islets in the liver and eventually produce enough insulin to control blood sugar.

Figure 4
Members of the Edmonton Protocol at the University of Alberta. The research team is also working on a procedure that would permit the transplant of islet cells into people with type 1 diabetes before the onset of physical complications, such as renal failure. A challenge regarding these transplants is finding an affordable supply of insulin-producing cells. At present, cadavers provide the only source of cells and the cost of processing islets from donors is formidable.

WEB Activity

Web Quest—Diabetes

Diabetes is on the rise in Canada and is becoming one of the leading causes of death. Having diabetes affects individuals, their families, as well as the health-care system. In this Web Quest, you will design a primer aimed at people recently diagnosed with diabetes. Your completed primer will explore the disease, current treatments, and the latest research.

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Adrenal Glands

The adrenal glands are located above each kidney. (The word adrenal comes from the Latin *ad*, meaning "to" or "at," and *renes*, meaning "kidneys.") Each adrenal gland is made up of two glands encased in one shell. The inner gland, the **adrenal medulla**, is surrounded by an outer casing, called the **adrenal cortex**. The medulla is regulated by the nervous system, while hormones regulate the adrenal cortex.

The adrenal medulla produces two hormones: epinephrine (also known as adrenaline) and **norepinephrine** (noradrenaline). The nervous system and the adrenal medulla are linked by the fact that both produce epinephrine. The hormone-producing cells within the adrenal medulla are stimulated by sympathetic nerves in times of stress.

In a stressful situation, epinephrine and norepinephrine are released from the adrenal medulla into the blood. Under their influence, the blood sugar level rises. Glycogen, a carbohydrate storage compound in the liver and muscles, is converted into glucose, a readily usable form of energy. The increased blood sugar level ensures that a greater energy reserve will be available for the tissues of the body. These hormones also increase heart rate, breathing rate, and cell metabolism. Blood vessels dilate, allowing more oxygen and nutrients to reach the tissues. Even the iris of the eye dilates, allowing more light to reach the retina—in a stress situation, the body attempts to get as much visual information as possible.

The adrenal cortex produces three different types of steroid hormones: the **glucocorticoids**, the **mineralocorticoids**, and small amounts of **sex hormones**. The glucocorticoids are associated with blood glucose levels. One of the most important of the glucocorticoids, **cortisol**, increases the level of amino acids in the blood in an attempt to help the body recover from stress. The amino acids are converted into glucose by the liver, thereby raising the level of blood sugar. Increased glucose levels provide a greater

adrenal medulla found at the core of the adrenal gland, produces epinephrine and norepinephrine

adrenal cortex outer region of the adrenal gland that produces glucocorticoids and mineralocorticoids

norepinephrine also known as noradrenaline, it initiates the fight-or-flight response by increasing heart rate and blood sugar

glucocorticoid any of the steroids produced by the adrenal cortex that help to regulate electrolyte and water balance

mineralocorticoid any of the sterioids produced by the adrenal cortex that regulate carbohydrate, lipid, and protein metabolism and inhibit the release of corticotrophin

sex hormone any hormone that affects the development and growth of sex organs

cortisol hormone that stimulates the conversion of amino acids to glucose by the liver

EXTENSION

Control of Cortisol Secretion
This animation shows how cortisol secretion is regulated by a negative feedback system.

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adrenocorticotropic hormone (ACTH) pituitary hormone that promotes cortisol release by the adrenal cortex; also called corticotropin

tropic hormone hormone that stimulates a specific target gland to secrete other hormones

energy source, which helps cell recovery. Any of the amino acids not converted into glucose are available for protein synthesis. The proteins can be used to repair damaged cells. In addition, fats in adipose tissue are broken down into fatty acids. Thus, a second source of energy is provided, helping conserve glucose in times of fasting. Under the influence of cortisol, blood glucose uptake is inhibited in many tissues, especially in the muscles. The brain is not affected though, since any significant decrease in glucose absorption of the brain would lead to convulsions.

Short-term and long-term stress responses are shown in **Figure 5**. The brain identifies stressful situations. The hypothalamus sends a releasing hormone to the anterior lobe of the pituitary, stimulating the pituitary to secrete **adrenocorticotropic hormone (ACTH)** (also called corticotropin). ACTH is a **tropic hormone**, which is a hormone that targets another endocrine gland. The blood carries the ACTH to the target cells in the adrenal cortex. Under the influence of ACTH, the cells of the adrenal cortex secrete mineralocorticoids and glucocorticoids (among them cortisol), which are

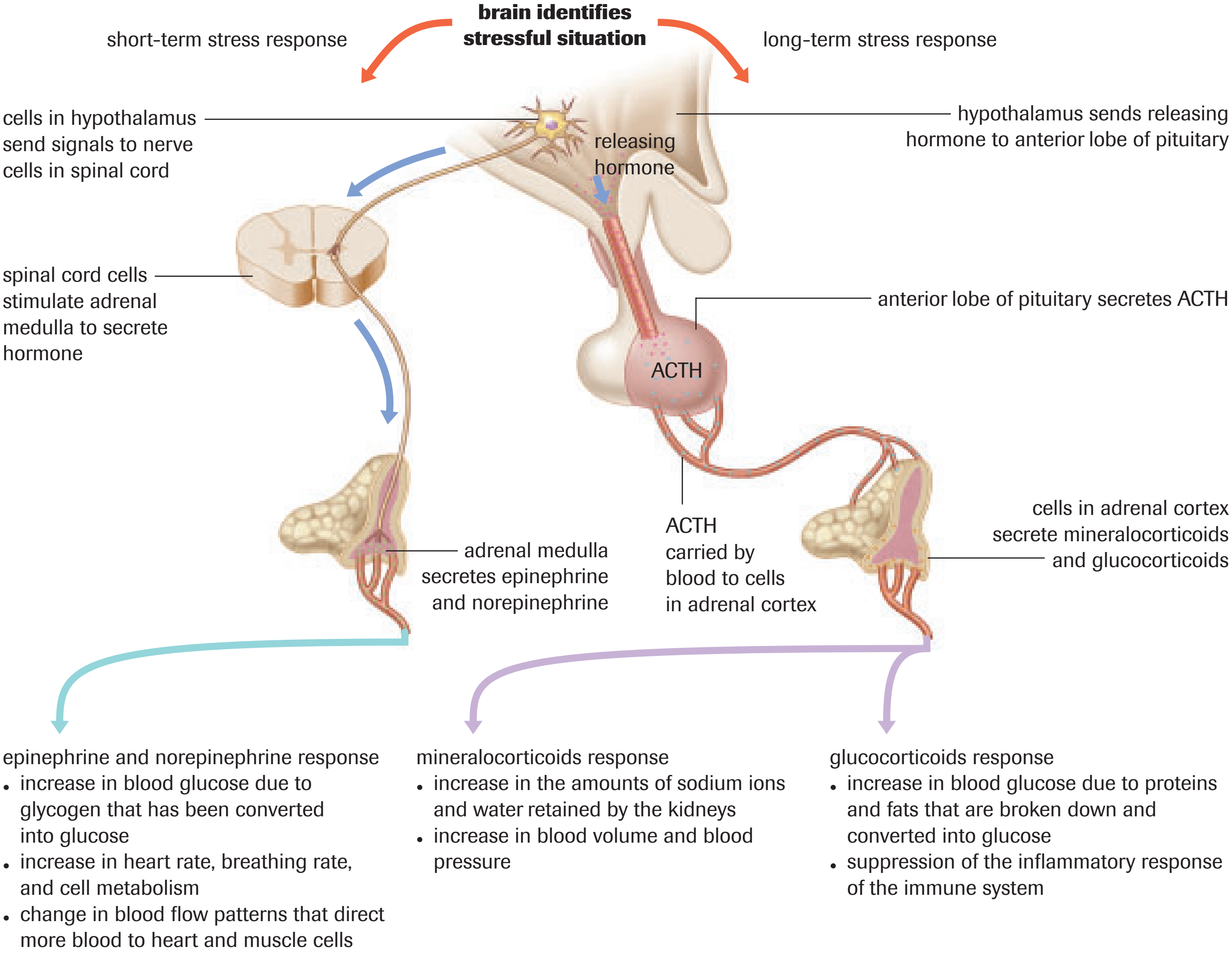

Figure 5
Most of the hormones released by the adrenal cortex in response to stress affect blood sugar levels. However, mineralocorticoids do not. They affect sodium and water levels in the blood.

carried to target cells in the liver and muscles. As cortisol levels rise, cells within the hypothalamus and pituitary decrease the production of regulatory hormones, and, eventually, the levels of cortisol begin to fall. This process is called a long-term stress response. The short-term stress response is regulated by the adrenal medulla, which secretes epinephrine and norepinephrine.

Aldosterone is the most important of the mineralocorticoids. Secretion of aldosterone increases sodium retention and water reabsorption by the kidneys, thereby helping to maintain body fluid levels. You will learn more about this hormone in Section 15.3. (You will explore the third type of hormone secreted by the adrenal cortex, sex hormones, in Unit 30 B.)

aldosterone hormone produced by the adrenal cortex that helps regulate water balance by increasing sodium retention and water reabsorption by the kidneys

Practice

4. What are the similarities and differences of the adrenal cortex and the adrenal medulla?
5. What are the effects of epinephrine and norepinephrine?
6. What is the effect of cortisol?

LAB EXERCISE 15.A

Effects of Hormones on Blood Sugar Levels

Report Checklist

○ Purpose	○ Design	● Analysis
○ Problem	○ Materials	○ Evaluation
○ Hypothesis	○ Procedure	○ Synthesis
○ Prediction	○ Evidence	

Blood sugar levels of a person with diabetes mellitus and a person without were monitored over a period of 12 h. Both ate an identical meal and performed 1 h of similar exercise.

Evidence

Use the data in **Figure 6** to answer the questions below.

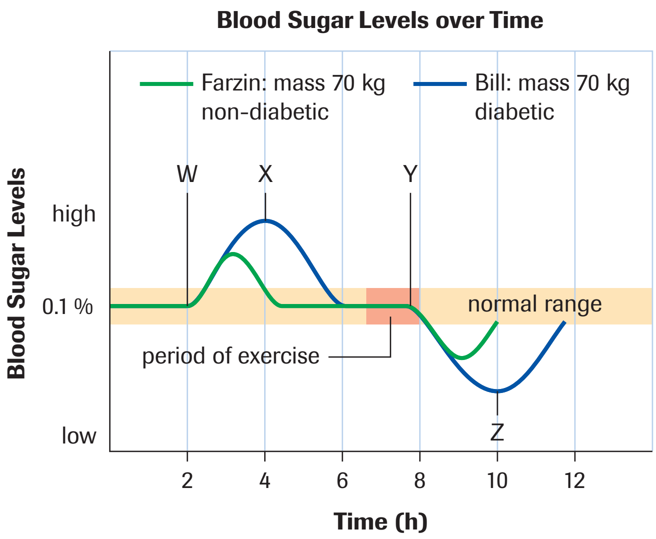

Figure 6
Blood sugar was monitored over 12 h.

Analysis

1. Which hormone injection did Bill receive at the time labelled X? Provide reasons for your answer.
2. What might have happened to Bill's blood sugar level if hormone X had not been injected? Justify your answer.
3. Explain why blood sugar levels rose at time W for Bill and Farzin.
4. Explain why their blood sugar levels begin to fall after time Y.
5. What hormone might Bill have received at time Z? Explain your answer.
6. Why is it important to note that both Farzin and Bill have the same body mass?
7. What differences in blood sugar levels are illustrated by the data collected from Bill and Farzin?
8. Formulate a hypothesis to explain why Bill and Farzin responded differently to the same environmental factors.

SUMMARY Hormones That Affect Blood Sugar

Table 1 Role of Hormones that Regulate Blood Sugar

Hormone	Location of hormone production	Effect
insulin	islets of Langerhans (pancreas)	• increases permeability of cells to glucose; increases glucose uptake • allows for the conversion of glucose to glycogen • brings about a decrease in blood sugar
glucagon	islets of Langerhans (pancreas)	• promotes the conversion of glycogen to glucose • brings about an increase in blood sugar
epinephrine and norepinephrine	adrenal medulla	• promotes the conversion of glycogen to glucose • brings about an increase in blood sugar • brings about an increase in heart rate and cell metabolism
cortisol (a type of glucocorticoid)	adrenal cortex	• promotes the conversion of amino acids to glucose • promotes the breakdown of fats to fatty acids • decreases glucose uptake by the muscles (not by the brain) • brings about an increase in blood sugar in response to stress

Section 15.2 Questions

1. List the hormones released from the pancreas and the adrenal glands, and indicate their control mechanisms.
2. What advantage is provided by increasing blood sugar above normal levels in times of stress?
3. How would high levels of adrenocorticotropic hormone (ACTH) affect secretions of cortisol from the adrenal glands? How would high levels of cortisol affect ACTH?
4. A number of laboratory experiments were conducted on laboratory mice. The endocrine system of mice is similar to that of humans. Brief summaries of the procedures are provided in **Table 2**.
   (a) In procedure 1, identify the gland that was removed and explain why the levels of ACTH increased.
   (b) In procedure 2, identify the hormone that was injected and explain why blood sugar levels decreased.
   (c) In procedure 3, identify the hormone that was affected and explain why urine production increased.
   (d) In procedure 4, identify the hormone that was injected and explain why blood glucose levels increased.
5. The incidence of diabetes in North America has risen dramatically in the last few decades. Research how changes in diet have affected the incidence of diabetes in the Aboriginal population.

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6. The North American lifestyle and diet are believed to be major contributors to type 2 diabetes. Many companies know that foods can be made more palatable to consumers by adding fats and sugars. Discuss the practice of adding fats and sugars to food products to increase sales.
7. Cortisol levels fluctuate throughout the day. Speculate why cortisol levels might be highest in the morning and lowest around midnight.

Table 2 Experiments Conducted on Laboratory Mice

Number	Procedure	Observation
1	gland removed	• urine output increased • Na^+ ion concentration in urine increased • ACTH level increased in blood
2	hormone injected	• blood glucose levels decreased
3	blood flow from the posterior pituitary reduced	• urine production increased
4	hormone injected	• glycogen converted to glucose in the liver • blood glucose increased

Hormones That Affect Metabolism 15.3

In this section, you will explore three different glands that affect metabolism: the **thyroid gland**, which produces the hormones triiodothyronine, thyroxine, and calcitonin; the **parathyroid glands**, which produce parathyroid hormone; and the anterior pituitary gland, which produces growth hormone (among many other regulatory hormones). The thyroid gland helps regulate body metabolism, or the rate at which glucose is oxidized. The parathyroid glands help regulate calcium levels in the blood and lower phosphate levels. Growth hormone (hGH) is one of a multitude of hormones produced by the anterior pituitary gland and influences the growth of long bones and accelerates protein synthesis.

thyroid gland a two-lobed gland at the base of the neck that regulates metabolic processes

parathyroid glands four pea-sized glands in the thyroid gland that produce parathyroid hormone to regulate blood calcium and phosphate levels

Thyroid Gland

Have you ever wondered why some people seem to be able to consume fantastic amounts without any weight change, while others appear to gain weight at the mere sight of food? Thyroid hormones and the regulation of metabolic rate can partly explain this anomaly. Approximately 60 % of the glucose oxidized in the body is released as heat. The remaining 40 % is transferred to ATP, the storage form for cell energy. This added energy reserve is often consumed during activity. Individuals who secrete higher levels of thyroid hormones oxidize sugars and other nutrients at a faster rate. Therefore, these individuals tend not to gain weight and tend to feel warm.

Individuals who have lower levels of thyroid hormones do not oxidize nutrients as quickly, and therefore tend not to break down sugars as quickly. Excess blood sugar is eventually converted into liver and muscle glycogen. However, once the glycogen stores are filled, excess sugar is converted into fat. It follows that the slower the blood sugar is used, the faster the fat stores are built up. People who secrete low amounts of thyroid hormones often experience muscle weakness, cold intolerance, and dry skin and hair. Not all types of weight gain are due to hypothyroidism (low thyroid secretions). In many cases, weight gain reflects a poor diet, lack of exercise, or genetics.

The thyroid gland (**Figure 1**) is located at the base of the neck, immediately in front of the trachea or windpipe. This gland produces two hormones, **thyroxine (T4)** and **triiodothyronine (T3)**, that regulate body metabolism and the growth and differentiation of tissues. Although both hormones appear to have the same function, approximately 65 % of thyroid secretions are thyroxine. In addition to thyroid hormones, the thyroid gland produces **calcitonin**, a hormone that acts on the bone cells to lower the level of calcium found in the blood.

DID YOU KNOW?

Hyperthyroidism

The overproduction of thyroxine by the thyroid gland results in hyperthyroidism. In hyperthyroidism, the fast oxidation of nutrients causes weight loss, elevated body temperature, and nervous behaviour. The most common cause of hyperthyroidism in Canada is an inherited disorder known as Graves' disease, or thyrotoxicosis. The condition is more common in females than in males.

thyroxine (T4) hormone produced by the thyroid gland that increases metabolism and regulates growth

triiodothyronine (T3) hormone produced by the thyroid gland that increases metabolism and regulates growth; contains three iodine atoms

calcitonin hormone produced by the thyroid gland that lowers calcium levels in the blood

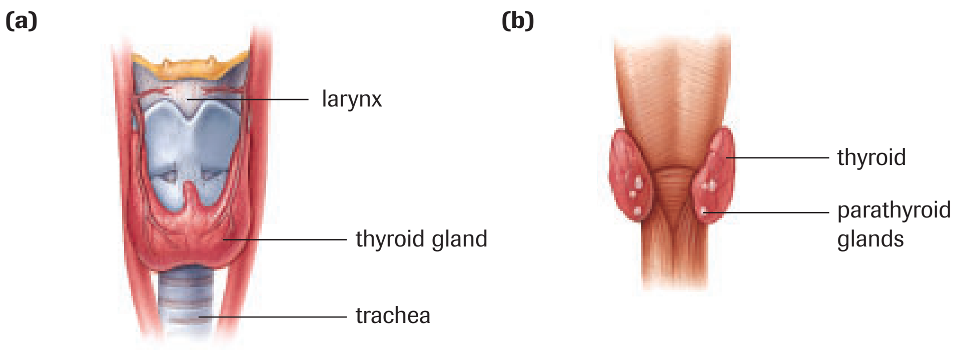

Figure 1
(a) anterior view of thyroid gland
(b) posterior view of thyroid gland

> **EXTENSION**
>
> **Hormonal Control of Metamorphosis**
> In amphibians, thyroid hormones regulate the rate at which metamorphosis occurs. In this activity, you will analyze and evaluate data from five different investigations and draw conclusions about the hormonal control of metamorphosis in three species of amphibian.
>
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Control of thyroid hormones, like many other hormones, is accomplished by negative feedback (**Figure 2**). Should the metabolic rate decrease, receptors in the hypothalamus are activated. Nerve cells in the hypothalamus secrete thyroid-releasing hormone (TRH), which stimulates the pituitary to release thyroid-stimulating hormone (TSH). Thyroid-stimulating hormone is carried by the blood to the thyroid gland, which, in turn, releases T3 and T4. T3 and T4 raise metabolism by stimulating increased use of sugar by body cells. Higher levels of T3 and T4 and TSH cause the pathway to be "turned off." T3, T4, and TSH inhibit the release of TRH from the hypothalamus, thus turning off the production of TSH from the pituitary.

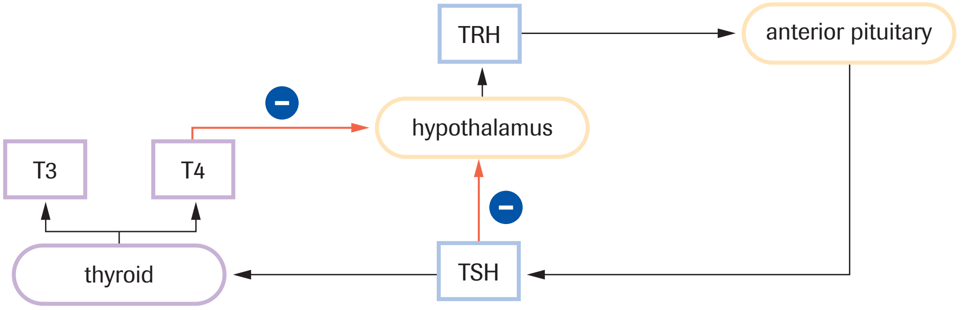

Figure 2
Feedback control loops in the secretion of thyroid hormones

Iodine is an important component of both thyroid hormones. A normal component of the diet, iodine is actively transported from the blood into the follicle cells of the thyroid. The concentration of iodine in the cells can be 25 times greater than that in the blood. Problems arise when iodine levels begin to fall. When inadequate amounts of iodine are obtained from the diet, the thyroid enlarges, producing a **goiter** (**Figure 3**).

goiter disorder that causes an enlargement of the thyroid gland

The presence of a goiter emphasizes the importance of a negative feedback control system. Without iodine, thyroid production and secretion of thyroxine drops. This causes more and more TSH to be produced and, consequently, the thyroid is stimulated more and more. Under the relentless influence of TSH, cells of the thyroid continue to develop, and the thyroid enlarges. In regions where the diet lacks iodine, the incidence of goiter remains high. In many countries, iodine is added to table salt to prevent this condition.

Figure 3
A goiter appears as a swelling in the neck area.

> **Practice**
>
> 1. How does thyroxine affect blood sugar?
> 2. List the symptoms associated with hypothyroidism and hyperthyroidism.

Parathyroid Glands

Four small parathyroid glands are hidden within the larger thyroid gland. Before these glands were discovered, surgeons treating goiters mistakenly removed the parathyroid glands along with sections of a hyperactive thyroid gland. Although the surgery relieved symptoms associated with an overly developed thyroid gland, the patients developed more serious problems. Rapid, uncontrolled muscle twitching, referred to as tetanus, signalled abnormal calcium levels. Tetanus occurs because the nerves become easily excited.

In most cases, nerves or other hormones regulate the endocrine glands. The parathyroid glands are one of the exceptions. The parathyroid glands respond directly to chemical changes in their immediate surroundings. With involvement from the thyroid glands, the parathyroid glands keep calcium levels in homeostasis.

Low calcium levels in the blood stimulate the release of **parathyroid hormone (PTH)** from the parathyroid glands and inhibits release of calcitonin from the thyroid (**Figure 4**). A rise in PTH levels causes the calcium levels in the blood to increase and phosphate levels to decrease. The hormone does this by acting on three different organs: the kidneys, the intestines, and the bones. PTH causes the kidneys and intestines to absorb more calcium while promoting calcium release from bone. (Approximately 98 % of the body's calcium is held in storage by the skeletal system.) The bone cells break down, and calcium is separated from phosphate ions. The calcium is reabsorbed and returned to the blood, while the phosphate is excreted in the urine. This helps conserve much of the body's calcium that is dissolved in plasma. PTH also enhances the absorption of calcium from undigested foods in the intestine. So, as PTH levels increase, the absorption of calcium ions also increases.

parathyroid hormone (PTH) hormone produced by the parathyroid glands, which will increase calcium levels in the blood and lower the levels of phosphates

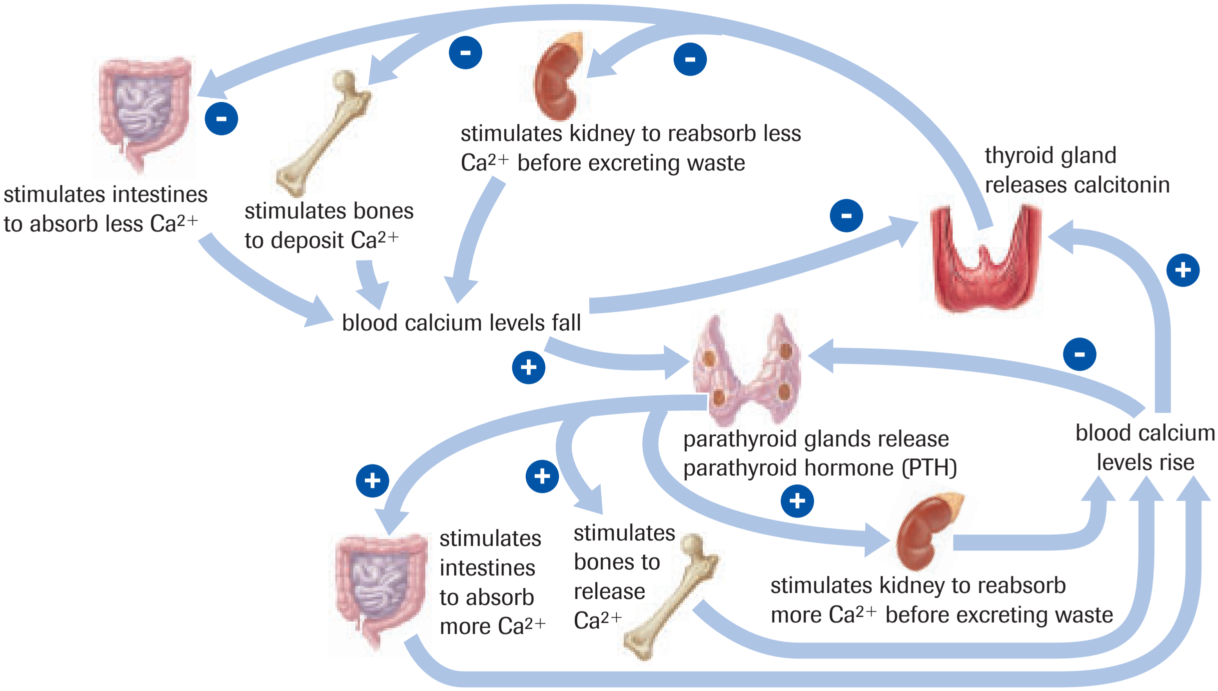

Figure 4

Low levels of blood calcium stimulate release of PTH from the parathyroid glands and inhibits release of calcitonin from the thyroid. PTH causes the kidneys and gut to retain calcium while promoting calcium release from bone. This causes blood calcium levels to rise, which in turn inhibits release of PTH from the parathyroid glands and stimulates release of calcitonin from the thyroid. Calcitonin causes the kidneys and gut to release calcium, while inhibiting calcium release from bone.

Figure 5
Improper bone formation can result from a diet lacking in fruits and vegetables.

Once calcium levels have risen, release of PTH is inhibited and release of calcitonin is stimulated. This causes the intestines, kidneys, and bones to reduce the amount of calcium they release to the blood, and calcium levels then begin to fall. This part of the feedback mechanism involving PTH and calcitonin ensures the blood calcium levels will not increase beyond the body's needs. Abnormally high levels of PTH or low levels of calcitonin can cause health problems. A strong, rigid skeleton is necessary for support, so prolonged breakdown of bone is dangerous. High calcium levels can cause it to collect in blood vessels or to form hard structures in the kidneys called kidney stones.

PTH also helps activate vitamin D. Low levels of vitamin D can cause a disease called rickets (**Figure 5**). With this disease, too little calcium and phosphorus are absorbed from foods and the bones develop improperly.

Growth Hormone (hGH)

Growth hormone (hGH) is produced by the anterior pituatary gland, and stimulates the elongation of the skeleton. The effects are most evident when the body produces too much (hypersecretion) or too little of it (hyposecretion). Hyposecretion of hGH during childhood can result in dwarfism; hypersecretion during childhood can result in gigantism. Hypersecretion in adulthood causes acromegaly, an abnormal bone growth in the hands, feet, and head. Although hGH affects most of the cells of the body, the effect is most pronounced on cartilage cells and bone cells.

Under the influence of growth hormone, cells of soft tissues and bone begin to grow by increasing the number of cells (hyperplasia) and increasing the size of cells (hypertrophy). Growth hormone increases cell size in muscle cells and connective tissues by promoting protein synthesis while inhibiting protein degradation or breakdown. Proteins in many cells, such as muscle, are in a constant state of breakdown and repair. Amino acid uptake increases, which in turn provides the raw materials for protein synthesis. This may help explain the link between declines in growth hormone production and the aging process. As a person ages, hGH production begins to decline and cellular repair and protein replacement are compromised. As the human body ages, protein is often replaced by fat, causing changes in the body's shape.

Growth hormone also has an important role in maintaining homeostasis. It increases fatty acid levels in the blood by promoting the breakdown of fats. Muscles use the fatty acids instead of glucose as a source of metabolic fuel. By switching fuel sources from glucose to fatty acids, growth hormone causes an increase in blood glucose levels. This is especially important for glucose-dependent tissues, such as the brain. The brain is unable to use fat as an energy source. This metabolic pathway is particularly important in times of prolonged fasting where glucose supplies are limited. Growth hormone increases the use of fat stores and promotes protein synthesis, which decreases the amount of fat stored in the body. This may help explain why quick growth spurts are often accompanied by a loss of body fat.

DID YOU KNOW?

Growth Hormone: Not Just for Growth

Even in adults, growth hormone is the most abundant hormone produced by the anterior pituitary gland. In addition to promoting growth, the hormone helps adjust blood sugar in times of prolonged fasting and enhances the immune system.

SUMMARY Hormones That Affect Metabolism

Table 2 Glands and Hormones Involved in Regulating Metabolism

Gland	Hormone	Effect on metabolism
thyroid	thyroxine (T4) and triiodothyronine (T3)	• regulates the rate at which glucose is oxidized within body cells
thyroid	calcitonin	• lowers calcium levels in the blood
parathyroid glands	parathyroid hormone (PTH)	• raises calcium levels in the blood
anterior pituitary	growth hormone (hGH)	• promotes protein synthesis by increasing the uptake of amino acids by cells • causes a switch in cellular fuels from glucose to fatty acids

Section 15.3 Questions

1. How do the pituitary and hypothalamus interact to regulate thyroxine levels?
2. What is a goiter and why does it create a problem?
3. Symptoms such as weight gain, increased sensitivity to cold, fatigue, and depression can indicate the thyroid gland is not working properly.
   (a) Choose one of the symptoms above and explain how the symptom can be linked to poor thyroid function.
   (b) Explain why eating foods, such as fish, green leafy vegetables, and dairy products, which have higher levels of iodine, may be helpful in preventing thyroid problems.
   (c) Explain why individuals with thyroid problems should avoid foods that block iodine absorption, such as soy and many uncooked vegetables.
4. How does parathyroid hormone (PTH) regulate blood calcium levels?
5. Why would removal of the parathyroid glands lead to tetany?
6. How would hyposecretion of growth hormone affect an individual?
7. The purpose of the parathyroid glands is to regulate the calcium level in our bodies within a very narrow range so that the nervous and muscular systems can function properly.
   (a) A person takes some calcium tablets. Draw a feedback loop showing how PTH regulates that person's calcium levels.
   (b) Hyperparathyroidism occurs when the parathyroids make too much PTH. Explain how this would affect blood calcium levels.
   (c) Explain how would hyperparathyroidism affect a person's bones.
8. Negative feedback control systems influence hormonal levels. The fact that some individuals have higher metabolic rates than others can be explained by the response of the hypothalamus and pituitary to thyroxine. Some feedback systems turn off quickly. Sensitive feedback systems tend to have comparatively lower levels of thyroxine; less sensitive feedback systems tend to have higher levels of thyroxine. One hypothesis attempts to link different metabolic rates with differences in the number of binding sites in the hypothalamus and pituitary. How might the number of binding sites for molecules along cell membranes affect hormonal levels? How would you go about testing the theory?
9. In July 1990, Dr. Daniel Rudman published a study in the prestigious *New England Journal of Medicine* proposing that injections of growth hormone could slow the aging process. Today, antiaging enthusiasts believe that growth hormone could be an antidote to the effects of decades of aging. Although researchers warn that the drug's long-term effects have not been documented and that the drug may not be suitable for everyone, speculation about the potentials of an antiaging drug abounds in both scientific and nonscientific communities. Comment on the social implications of using a drug to slow aging.
10. Bovine somatotropin (BST) is a growth hormone now produced by gene recombination. BST can increase milk production in cows by as much as 20 % by increasing nutrient absorption from the bloodstream into the cow's milk. Should BST be used? Why might some individuals be concerned?

15.4 Hormones Affecting Water and Ion Balance

The body adjusts for increased water intake by increasing urine output. Conversely, it adjusts for increased water loss or decreased water intake by reducing urine output. These homeostatic adjustments involve the nervous system and two different hormones of the endocrine system, antidiuretic hormone (ADH) and aldosterone.

ADH and Water Balance

antidiuretic hormone (ADH) a hormone that causes the kidneys to increase water reabsorption

osmoreceptors sensory receptors in the hypothalamus that detect changes in the osmotic pressure of the blood and surrounding extracellular fluids (ECF)

The main function of **antidiuretic hormone** (**ADH**) is to conserve body water by reducing urine output. As you have learned previously, diuresis is urine formation and so antidiuresis is the stopping of urine formation, hence the name *antidiuretic* hormone.

How does the body know when to conserve water? There are sensory receptors in the hypothalamus called **osmoreceptors**, which detect changes in osmotic pressure in body fluids.

When you decrease water intake or increase water loss—by sweating, for example—blood solutes become more concentrated. This increases the blood's osmotic pressure. Consequently, water moves into the blood, causing the osmoreceptor cells of the hypothalamus to shrink (**Figure 1**). When this happens, the osmoreceptors stimulate the posterior pituitary gland to release ADH, which is carried by the bloodstream to the kidneys. ADH causes the kidneys to reabsorb more water and thus produce a more concentrated urine. Conserving water prevents the osmotic pressure of the blood from increasing any further.

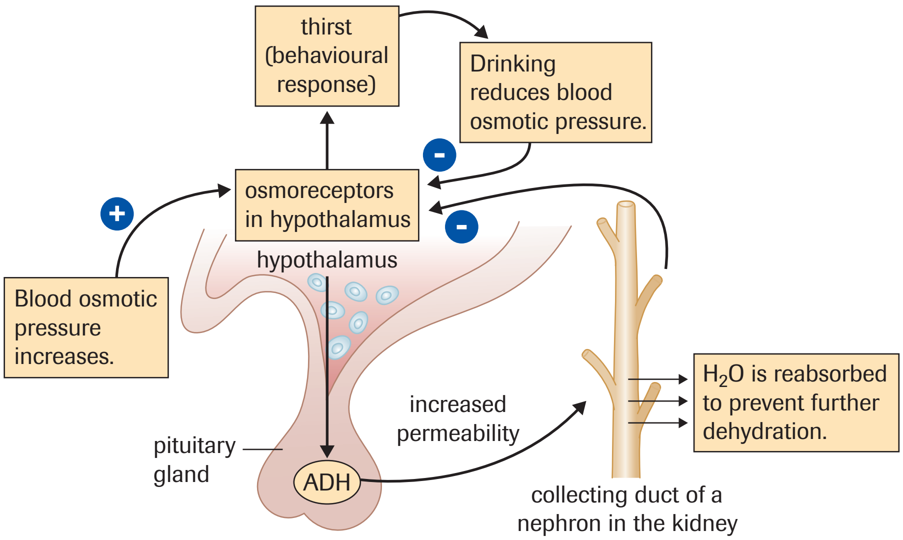

Figure 1
By increasing water reabsorption in the kidneys, ADH helps conserve body water. The osmoreceptors in the hypothalamus initiate the thirst response.

DID YOU KNOW?

Alcohol Affects Fluid Levels
Alcohol consumption decreases the release of ADH. Some of the symptoms experienced the day following excessive alcohol consumption can be attributed to increased water loss through urine and decreased body fluid levels.

As the osmoreceptors shrink, they also stimulate the sensation of thirst. Drinking water in response to feeling thirsty is a behavioural response rather than a physiological response. As more water is taken in, it is absorbed by the blood and the concentration of solutes in the blood decreases. The greater the volume of water consumed, the lower the osmotic pressure of the blood. As the blood becomes more dilute, fluids move from the blood into the hypothalamus. As a result, the osmoreceptors swell and so they stop stimulating the pituitary gland to release ADH. As ADH levels drop, the tubules in the kidney reabsorb less water. Homeostasis is restored.

ADH and the Nephron

Approximately 85 % of the water filtered into the nephron is reabsorbed in the proximal tubule. Although the proximal tubule is very permeable to water, this permeability does not extend to other segments of the nephron (**Figure 1**, previous page). The remaining 15 % of the water filtered into the nephron will be lost if no ADH is present. ADH makes the upper part of the distal tubule and collecting duct permeable to water. When ADH makes the cell membranes permeable, the high concentration of NaCl in the intercellular spaces creates an osmotic pressure that draws water from the upper section of the distal tubule and collecting duct. As water passes from the nephron to the intercellular spaces and the blood, the urine remaining in the nephron becomes more concentrated. It is important to note that the kidneys control only the last 15 % of the water found in the nephron. By varying water reabsorption, the kidneys regulate the osmotic concentrations of body fluids.

Diabetes Insipidus

Diabetes insipidus is the most common disease associated with ADH and its main characteristic is the production of excessive amounts of urine (as much as 16 litres a day). It can be caused by the failure of the posterior pituitary to secrete enough ADH or by the failure of the kidney to respond to ADH. It is not life threatening so long as the person has enough water to drink.

Aldosterone, Blood Pressure and Blood Volume

Conditions that lead to increased fluid loss can decrease blood pressure, reducing the delivery of oxygen and nutrients to tissues. Near the glomerulus is a complex of cells called the **juxtaglomerular apparatus (JGA)**. Blood pressure receptors in the juxtaglomerular apparatus (**Figure 2**, next page) detect changes in blood pressure. When blood pressure is low, specialized cells within the structure release renin, an enzyme that converts angiotensinogen, a plasma protein produced by the liver, into angiotensin.

Angiotensin has two important functions. First, it causes constriction of blood vessels. Blood pressure increases when the diameter of blood vessels is reduced. Second, angiotensin stimulates the release of the hormone aldosterone from the adrenal cortex. Aldosterone is then carried in the blood to the kidneys, where it acts on the cells of the distal tubule and collecting duct to increase Na^+ reabsorption. This causes blood volume and blood pressure to increase. Not surprisingly, as Na^+ reabsorption increases, the osmotic pressure increases and more water moves out of the nephron into the blood by osmosis. This pathway is called the renin-angiotensin-aldosterone system (RAAS).

At first glance, it might appear that the role of ADH is the same as the renin-angiotensin-aldosterone system. Both increase water reabsorption. However, ADH responds to an increase in osmotic pressure of the blood. For example, when the body is dehydrated due to lack of water. The renin-angiotensin-aldosterone system responds when the blood volume is reduced but the osmotic pressure of the blood remains the same. For example, when there is a large loss of body fluid, perhaps from severe diarrhea or from a hemorrhage.

CAREER CONNECTION

Pharmacist

Monitoring and managing a patient's drug therapy is an essential component of pharmacists' work. They also educate caregivers and health professionals about disease management and drug research related to the health and well-being of individuals under the care of a physician. Specialized courses in biology and chemistry are required to become a pharmacist.

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juxtaglomerular apparatus (JGA) a functional unit near a kidney glomerulus that controls renin release in response to changes in blood pressure

EXTENSION

Blood Osmolarity and the Role of Antidiuretic Hormone

Listen to a discussion of blood osmolarity, and the homeostatic interactions that occur among the blood, the hypothalamus, and the collecting ducts of the kidneys.

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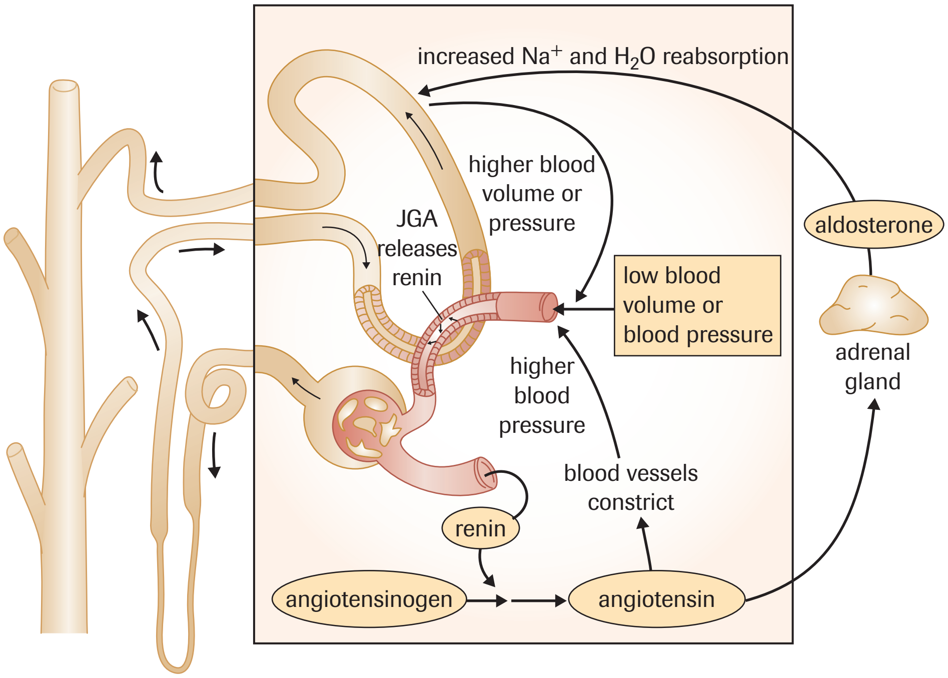

Figure 2
The hormone aldosterone maintains homeostasis by increasing Na^+ and water reabsorption.

WEB Activity

Case Study—Homeostasis and Space Travel

As humans spend more time in space, scientists have found that the microgravity environment changes the ability of the body to maintain homeostasis. Astronauts who spend substantial periods in space are at highest risk of developing hypercationa, a condition that causes kidney stone formation. Aldosterone and ADH work together to adjust urine volume and reabsorption of salts by the kidney. In this activity, you will infer the role of ADH and aldosterone from data on blood and urine composition, and relate it to the changes in homeostasis during space flight.

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SUMMARY *Hormones Affecting Water and Ion Balance*

- Osmoreceptors in the hypothalamus stimulate the release of ADH from the posterior pituitary in response to increased osmotic pressure in the blood.
- ADH causes the distal tubules and collecting ducts of the kidneys to reabsorb more water, which makes the blood less concentrated.
- Aldosterone forms part of the renin-angiotensin-aldosterone system, which is activated by low blood pressure or low blood volume.
- Aldosterone causes the distal tubules to reabsorb more Na^+ ions and water, which increases blood volume and blood pressure.

Section 15.4 Questions

1. In **Figure 3**, labels 1 and 2 represent two hormones that directly affect the permeability of the kidney. Identify these hormones and state their functions.

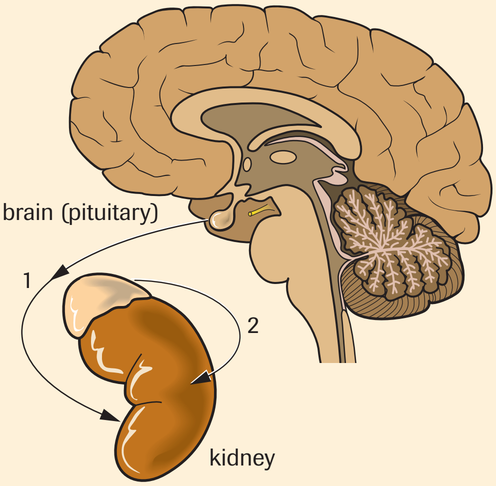

Figure 3

2. Describe the mechanism that regulates the release of ADH.
3. Where is the thirst centre located?
4. Describe the physiological adjustment to increased osmotic pressure in body fluids.
5. Discuss the mechanism by which aldosterone helps to maintain blood pressure.
6. Draw a flow chart that shows why the release of ADH is a negative feedback mechanism.
7. An experiment was performed to determine the effect of a drug, labelled X, on human metabolism. The rate of metabolism can be measured indirectly by monitoring changes in body temperature. Four comparable groups of 50 individuals each were used in the experiment. At the same time each day, all group members were given a dosage of the drug, except for group 4, which was given a placebo that did not contain the drug. Urine output and urea concentrations in urine were monitored one hour after the drug was taken. Each group member was monitored for changes in body temperature and in the volume of secretion from the thyroid gland. The observations are recorded in **Table 1**.
   (a) What controls were used for this experiment?
   (b) Identify the dependent and independent variables for this experiment.
   (c) Using the information provided, does the drug increase metabolic rate? Justify your answer.
   (d) What evidence suggests that drug X exerts a negative feedback response?
   (e) What evidence suggests that ADH and/or aldosterone were released in response to the drug?
   (f) What indirect evidence could you collect that would confirm whether aldosterone was being released?

Table 1 Effects of Different Dosages of Drug X on Metabolism

Group	Dosage of Drug X*	Change in body temp. (°C)	Perspiration	Urea g/100 mL of urine	Urine output mL	Thyroid gland output*
1	1	+0.2	slight increase	1.55	750	0.9
2	10	+0.9	moderate increase	2.01	600	9.8
3	100	+1.2	large increase	2.79	410	97.2
4	placebo	0.0	no change	1.55	810	0.0

* (10^{-6}g/50 kg of body mass)

15.5 Adjustments to Stress

Figure 1
Dr. Hans Selye (1907–1982), the Austrian-born Canadian endocrinologist, was an authority on the link between psychological stress, biochemical changes, and disease.

Dr. Hans Selye (**Figure 1**) was one of the first to identify the human response to long-term stress from a noxious stimulus. According to Selye, a general adaptation syndrome results from exposure to prolonged stress brought on by a disruption of the external and internal environment. When stressful stimulus is identified, both the endocrine system and nervous system make adjustments that enable the body to cope with the problem. The nervous system rapidly adjusts to stress by increasing heart rate and diverting blood to the needed muscles. Although somewhat slower in response, hormones from the endocrine system provide a more sustained response to the stimulus. (See **Figure 5** in Section 15.2, page 482.) **Table 1** summarizes some of the hormonal changes in response to stress.

Table 1 Hormonal Changes in Response to Stress

Hormone	Change	Adjustment
epinephrine	increases	• mobilizes carbohydrate and fat energy stores • increases blood glucose and fatty acids • accelerates heart rate and the activity of the respiratory system
cortisol	increases	• mobilizes energy stores by converting proteins to glucose • elevates blood amino acids, blood glucose, and blood fatty acids
glucagon	increases	• converts glycogen to glucose
insulin	decreases	• decreases the breakdown of glycogen in the liver

Stress hormones provide more blood glucose to cope with the elevated energy requirements brought on by stress. Remember that the primary stimulus for insulin secretion is a rise in blood glucose. If insulin release was not inhibited during a stress response, the hyperglycemia caused by stress would lead to an increased secretion of insulin, which would then lower blood glucose. Consequently, the elevated blood glucose would not be sustained to deal with the continued stress.

In addition to hormones that regulate blood sugar during stress, other hormones regulate blood pressure and blood volume. The nervous system activates the renin–angiotensin–aldosterone pathway in response to reduced blood flow to the kidneys. By increasing Na^+ reabsorption, the kidneys help maintain increased fluid volume. This helps sustain adequate blood pressure during stress. In addition, the stressor activates the hypothalamus, which causes an increased release of antidiurectic hormone (ADH). ADH will further increase water reabsorption from the nephron to help maintain body fluids.

During athletic competition, the accelerated cardiovascular activity provides greater oxygen delivery to the tissues for cellular respiration. Increases in blood sugar and fatty acid levels provide more fuel for metabolic processes. In turn, the greater supply of reactants can provide more ATP for activity.

It is more difficult to adjust to emotional or psychological stress because the increased energy supply is not always used. Although increased nerve activity requires greater energy, the ATP provided by homeostatic adjustment often outstrips demand. Prolonged exposure to high blood glucose, high blood pressure, and an elevated metabolic rate

often causes a readjustment of control systems to permit the higher operating range. As shown in **Table 2**, operating with elevated blood sugar, blood pressure, and heart rate creates more problems for the body.

Table 2 Problems Associated with Long-Term Stress

New operating limit	Problem created
higher blood sugar	• alters osmotic balance between blood and extracellular fluids; can lead to increased fluid uptake by the blood and increased blood pressure • increased water loss from nephron
increased blood pressure	• possible rupture of blood vessels due to higher pressure • increased blood clotting
increased heart rate	• can lead to higher blood pressure • possible destruction of heart muscle

Prostaglandins

Prostaglandins are a group of hormones, but unlike other hormones, they do not travel to other sites in the body. They act on the cells that produced them, and virtually all cells in the body produce them. When a tissue is damaged (stressed), the tissue's cells produce prostaglandins in response. Prostaglandins stimulate inflammation at the damage site, increase blood flow, and stimulate platelets to form clots in damaged blood vessels. They also play a role in producing a fever and cause an increase in the perception of pain.

prostaglandins a group of hormones that act on the cells that produce them in response to cell damage; produced by most cells

Interestingly, aspirin is an effective reducer of fever, pain, and inflammation. It does this by blocking enzyme involved in prostaglandin production. Because aspirin reduces prostaglandin production, blood does not clot as easily. Thus aspirin is often prescribed to prevent clotting in people with heart disease. One of the downsides of aspirin is that if a person is injured while taking it, they may bleed more profusely.

Chemically Enhanced Sports Performance

Strenuous exercise places stress on body systems, which compensate by delivering more fuel and oxygen to the tissues. Long before they were used in sport, ancient people documented how different drugs could mirror hormones produced by the body to affect heart rate, breathing rate, and blood pressure. Caffeine, for example, was found to produce many of the same effects as epinephrine (adrenaline), by increasing heart rate, blood pressure, and alertness.

The quest to gain an advantage began in the 1950s when weight lifters began injecting themselves with **anabolic steroids**. Anabolic steroids are designed to mimic many of the muscle-building traits of the sex hormone testosterone. Although still controversial, some have reported that anabolic steroids can provide athletes with greater lean muscle development and increased strength and, therefore, are advantageous for weightlifting and shorter sprints. However, anabolic steroids do not provide increased agility or skill level, nor do they enhance the ability of the cardiovascular system to deliver oxygen. In fact, they would be detrimental to athletes who need to sustain a high level of aerobic activity over a longer duration, such as marathon runners or cyclists. Although some athletes claim that steroids provide faster recovery from injury, and, therefore, allow more rigorous training, these claims have not been conclusively proven by laboratory studies. Whether advantageous or not, these types of drugs have been banned from competitive sports. During the 1988 Olympics, Canadian sprinter Ben Johnson was disqualified and stripped of a gold medal for using Stanozolol, an anabolic steroid.

anabolic steroids substances that are designed to mimic many of the muscle-building traits of the sex hormone testosterone

A number of health risks have been linked to the extended use of large dosages of anabolic steroids (**Figure 2**). Of particular interest to teens is that anabolic steroids prematurely fuse growth plates in the long bones, thereby reducing the height potential of the individual. Psychological effects, such as mood swings and feelings of rage, have also been documented.

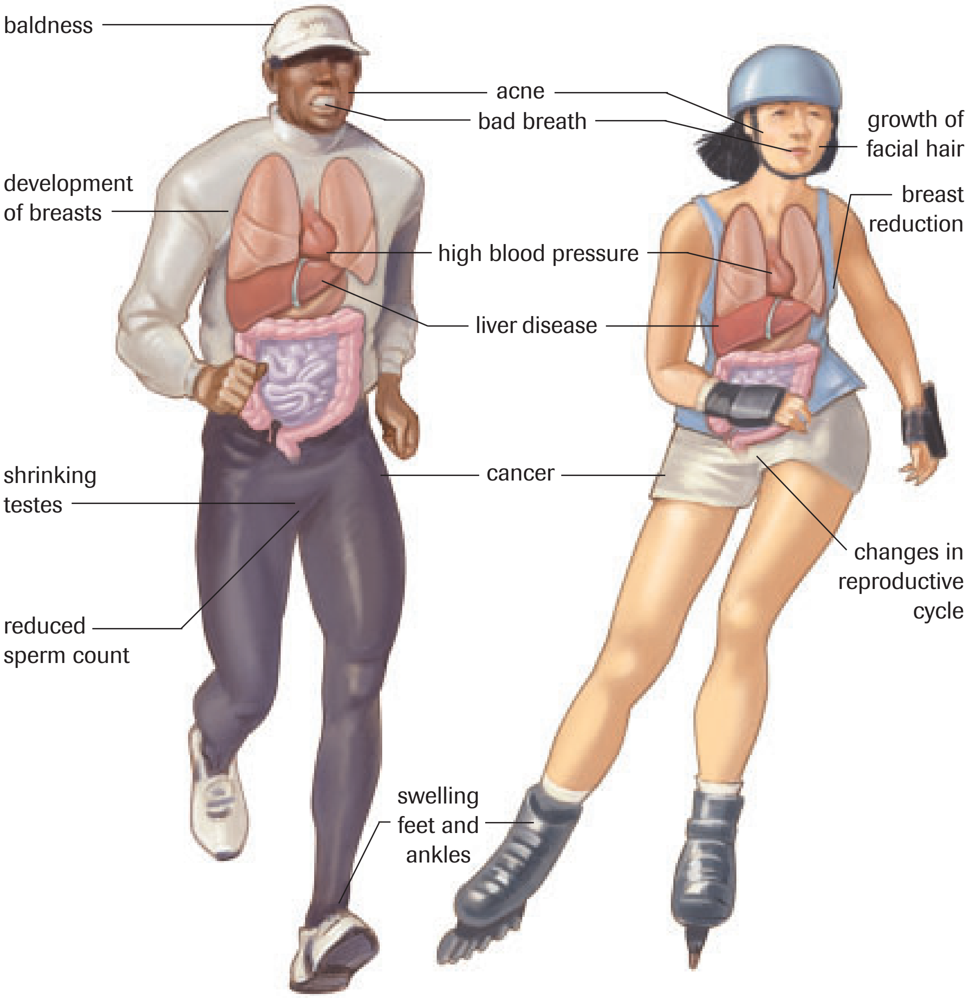

Figure 2
Effects of prolonged anabolic steroid use

Today, athletes have access to a myriad of drugs that do more than just increase strength. Sharpshooters and archers have used beta blockers to slow the heartbeat, which helps to steady their aim and calm jangled nerves. Endurance athletes can gain an advantage by taking erythropoietin (EPO). Human growth hormone decreases fat mass and promotes protein synthesis for muscle development; the enhancement of repair and growth increases strength and permits more vigorous training.

Because the body naturally produces hGH and EPO, they are difficult to detect with standard testing methods. More sophisticated methods must be used to detect small chemical differences between natural and artificial growth hormone. (Artificial growth hormone is synthesized by genetically modified bacteria.) Esters of testosterone are another group of muscle-building drugs that are difficult to detect. The esters slow the metabolism of testosterone by the body, keeping it in the body longer. Normally, testosterone would be metabolized in a few hours. The ester and testosterone raise little suspicion when testing is performed because both occur naturally in the body.

EXPLORE an issue

Protecting Athletes

Winning high-profile sporting competitions such as the Tour de France or Olympic events can be worth millions of dollars in endorsements to the winner (in addition to the fame and adoration they receive in their home countries). It is not surprising that athletes will do almost anything to gain an advantage over their competitors.

Drug testing began at the 1968 Olympics, a year after a British cyclist died of heart failure at the Tour de France after taking a stimulant. The International Olympic Committee (IOC) banned the use of anabolic steroids in 1975. But detection methods did not keep pace with masking agents. A sensitive test for steroids was finally developed in 1983. In 1990, the IOC added testosterone and caffeine to its banned substance list.

Today the most prevalent banned substances are synthetic hormones such as erythropoietin (EPO) (mentioned in the Chapter 15 introduction, page 468). A recombinant version of EPO was originally developed to treat renal failure in dialysis patients. However, some athletes now use it to gain a competitive edge. EPO has been linked to deaths of cyclists, cross-country skiers and runners. In 2006, cyclist Floyd Landis was stripped of his title of winner of the Tour de France when tests revealed he had been taking a synthetic form of testosterone.

Issue Checklist

- ○ Issue
- ○ Design
- ● Analysis
- ● Resolution
- ● Evidence
- ● Evaluation

Statement

Not enough is being done to prevent the use of banned substances in sports.

In your group, research the issue. Search for information in newspapers, periodicals, CD-ROMs, DVDs, and on the Internet.

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- Prepare a list of points and counterpoints for your group to discuss. You might consider these questions:
  - (i) Are some countries complicit in helping athletes hide positive drug tests? Are athletes being sacrificed for national glory?
  - (ii) Are organizers of events compromised in their desire to identify users of banned substances by continually pushing for more records?
  - (iii) What improvements could be made to help eliminate banned drugs from athletics?
- Develop and reflect on your opinion.
- Communicate your views in an appropriate manner.

SUMMARY Adjustments to Stress

- The endocrine and nervous systems interact to help the body cope with stress.
- Prostaglandins are produced by cells that have been damaged and they produce a variety of physiological effects in the damaged cells.
- Anabolic steroids are one of many chemicals used to enhance athletic performance.

Section 15.5 Questions

1. Both the nervous system and endocrine system respond to stress. Explain the benefits of each system's response.
2. Explain what advantage is gained by elevating blood sugar and blood pressure in times of stress.
3. Why is the secretion of insulin reduced in times of stress?
4. Explain the roles of the adrenal medulla and adrenal cortex in times of stress.
5. What are prostaglandins?
6. You have received a bad wound on your arm. Describe the effects prostaglandins have on the wounded area.
7. What are anabolic steroids? Outline their benefits to an athlete and their dangerous side effects.
8. Explain why a marathon runner would be unlikely to take growth hormone or anabolic steroids.
9. Why would erythropoietin (EPO) give an athlete competing in an endurance event an unfair advantage?
10. Why is it difficult to detect banned drugs like growth hormone and EPO?
11. The International Olympic Committee has banned performance-enhancing drugs. Research the classes of banned drugs. Describe the advantages and side effects of one drug in each class.

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INVESTIGATION 15.1

Identification of Hyperglycemia

Report Checklist

● Purpose	● Design	● Analysis
○ Problem	○ Materials	● Evaluation
● Hypothesis	○ Procedure	● Synthesis
● Prediction	● Evidence	

In this investigation, you will use simulated urine samples to determine how urinalysis is used to identify hyperglycemia and diabetes. Before the investigation, record the purpose of the investigation and then predict what colour(s) you expect to observe in the urine samples using Benedict's test and glucose test tape that will indicate diabetes. Outline the criteria you used to make your decision. When you have gathered and recorded the evidence, analyze it and identify any subjects that might have diabetes. Explain any other reasons there may be for a positive test.

Problem

How is urinalysis used to identify hyperglycemia diabetes?

Materials

safety goggles
laboratory apron
4 test tubes
wax pen
10 mL graduated cylinder
Benedict's solution
medicine dropper
4 samples of simulated urine
test-tube rack
400 mL beaker
beaker tongs
hot plate
test-tube clamp
distilled water
forceps
glucose test tape

Benedict's solution is toxic and an irritant. Avoid skin and eye contact. Wash all splashes off your skin and clothing thoroughly. If you get any chemical in your eyes, rinse for at least 15 minutes and inform your teacher.

Procedure

Part 1: Benedict's Test

Benedict's solution identifies reducing sugars. Cupric ions in the solution combine with sugars to form cuprous oxides, which produce colour changes (**Table 1**).

Table 1 Benedict's Test Colour Chart

Colour of solution	Glucose concentration
blue	0.0 %
light green	0.15 %–0.5 %
olive green	0.5 %–1.0 %
yellow-green to yellow	1.0 %–1.5 %
orange	1.5 %-2.0 %
red to red-brown	2.0 %+

1. Label the four test tubes A, B, C, and D. Use a 10 mL graduated cylinder to measure 5 mL of Benedict's solution into each test tube.
2. With a medicine dropper, add 10 drops of urine from sample A to test tube A. Rinse the medicine dropper and repeat for samples B, C, and D.
3. Fill a 400 mL beaker with approximately 300 mL of tap water. Using beaker tongs, position the beaker on a hot plate. The beaker will be used as a hot-water bath. Use the test-tube clamp to place the test tubes in the hot-water bath for 5 min.
4. With the test-tube clamp, remove the samples from the hot-water bath. Record the final colours of the solutions.

Part 2: Glucose Test Tape

The reducing sugar in the urine will react with copper sulfate to reduce cupric ions to cupric oxide. The chemical reaction is indicated by a colour change of the test tape. **Table 2** provides quantitative results.

Table 2 Glucose Test Tape Colour Chart

Colour of solution	Glucose concentration
blue	0.0 %
green	0.25 %–0.5 %
green to green-brown	0.5 %–1.0 %
orange	2.0 %+

5. Clean the four test tubes and place 10 drops of distilled water into each of them.
6. Add five drops of urine to each of the appropriately labelled test tubes. Place the test tubes in a test-tube rack.
7. Use forceps to dip test tape into each of the test tubes. Record the final colours of the test tape.

INVESTIGATION 15.1 *continued*

Evaluation

(a) Describe any difficulties you had in carrying out your investigation.

(b) Explain the advantage of conducting two different tests. Which test was more appropriate? Explain your answer.

(c) Today, people with diabetes test their blood to monitor sugar levels. Explain why blood tests are preferred for people with diabetes. Why weren't blood tests carried out in this investigation?

Synthesis

(d) Why is insulin not taken orally?

(e) Explain why people with diabetes experience the following symptoms: low energy levels, large volumes of urine, the presence of acetone on the breath, and acidosis (blood pH becomes acidic).

(f) Why might the injection of too much insulin be harmful?

(g) Explain how you would help someone who had taken too much insulin.

EXTENSION

CBC radioONE QUIRKS & QUARKS

Fixing Diabetes

Dr. Alex Rabinovitch (University of Alberta) has come up with a new solution addressing the main problem of juvenile diabetes—that the insulin-producing cells, called beta cells, have been destroyed. He's found that he can expose a pancreas to certain chemical growth factors and stimulate it to produce more beta cells. This research opens up the possibility that, in the future, a diabetic will be able to stimulate her or his own pancreas to build new beta cells and regain the ability to make insulin.

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Chapter 15 SUMMARY

Outcomes

Knowledge

- identify the principal endocrine glands of the human organism (15.1, 15.2, 15.3)
- describe the function of the hormones of the principal endocrine glands (15.1, 15.2, 15.3, 15.4)
- explain the metabolic roles hormones may play in homeostasis (15.2, 15.3, 15.4, 15.5)
- explain how the endocrine system allows human organisms to sense their internal environment and respond appropriately (15.1, 15.2, 15.3, 15.4, 15.5)
- compare the endocrine and nervous control systems and explain how they act together (i.e., stress and the adrenal gland) (15.2, 15.3, 15.5)
- describe, using an example, the physiological consequences of hormone imbalances (15.2, 15.3, 15.4)

STS

- explain that science and technology are developed to meet societal needs and expand human capability (15.1, 15.2, 15.5)
- explain that science and technology have both intended and unintended consequences for humans and the environment (15.1, 15.3, 15.5)

Skills

- ask questions and plan investigations by formulating a hypothesis, from published data, on an environmental factor that can be detected and responded to by humans (15.4)
- conduct investigations and gather and record data and information (15.2, 15.4)
- analyze data and apply models by: inferring the role of ADH and aldosterone in maintenance of water and ions using data on blood and urine composition (15.4); and, inferring the role of insulin in regulation of blood sugar by investigating the presence of glucose in simulated urine and comparing with normal blood glucose levels (15.2)

Key Terms

15.1

homeostasis
dynamic equilibrium
negative feedback
positive feedback
hormones
endocrine hormones
insulin
human growth hormone (hGH)
epinephrine (adrenaline)
pituitary gland
releasing hormone
inhibiting factor

15.2

islets of Langerhans
glucagon
diabetes
adrenal medulla
adrenal cortex
norepinephrine
glucocorticoid
mineralocorticoid
sex hormone
cortisol
adrenocorticotropic hormone (ACTH)
tropic hormone
aldosterone

15.3

thyroid gland
parathyroid glands
thyroxine (T4)
triiodothyronine (T3)
calcitonin
goiter
parathyroid hormone (PTH)

15.4

antidiuretic hormone (ADH)
osmoreceptors

15.5

prostaglandins
anabolic steroids

MAKE a summary

1. Sketch the human endocrine system and show how the system maintains homeostasis in response to stress. Use as many of the key terms as possible.
2. Revisit your answers to the Starting Points questions at the start of the chapter. Would you answer the questions differently now? Why?

Go To www.science.nelson.com

The following components are available on the Nelson Web site. Follow the links for *Nelson Biology Alberta 20–30*.

- an interactive Self Quiz for Chapter 15
- additional Diploma Exam-style Questions
- Illustrated Glossary
- additional IB-related material

There is more information on the Web site wherever you see the Go icon in the chapter.

UNIT 30 A PERFORMANCE TASK

Determining the Effects of Caffeine on Homeostasis

In this Performance Task, you will investigate the effects caffeine has on an invertebrate and how it affects homeostasis. Go to the 30 A Performance Task link on the Nelson web site to complete this task.

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Many of these questions are in the style of the Diploma Exam. You will find guidance for writing Diploma Exams in Appendix A5. Science Directing Words used in Diploma Exams are in bold type. Exam study tips and test-taking suggestions are on the Nelson Web site.

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Part 1

1. Which of the following describes a negative feedback reaction?
   A. Glucagon stimulates the release of glucose from the liver, which increases blood glucose.
   B. Insulin stimulates cells to absorb glucose, which inhibits the release of insulin.
   C. The hypothalamus releases TRH, which travels to the pituitary gland initiating the release of TSH, which stimulates the release of thyroxine from the thyroid gland.
   D. Calcitonin is released from the thyroid gland and blood calcium levels decrease.

2. Glucagon is produced in an organ and affects target cells that are in another part of the body. The organ of production and the location of the target cells are, respectively,
   A. the adrenal medulla and the adrenal cortex
   B. the liver and the pancreas
   C. the pituitary and the adrenal medulla
   D. the pancreas and the liver

3. Two hormones that adjust body systems for short-term stress and long-term stress are, respectively,
   A. thyroxine and PTH
   B. estrogen and growth hormone
   C. epinephrine and cortisol
   D. TSH and epinephrine

4. A hypersecretion of growth hormone (acromegaly) in an adult would result in which of the following symptoms?
   A. decreased growth of the long bones, causing dwarfism
   B. increased growth of the long bones, causing gigantism
   C. decreased heart rate and an increased amount of fat tissue
   D. widening of the fingers and toes and broadening of the facial bones

5. A person with diabetes could be identified by which of the following symptoms?
   A. increased blood sugar and decreased urine output
   B. increased blood sugar and increased urine output
   C. decreased blood sugar and decreased urine output
   D. decreased blood sugar and increased urine output

6. A laboratory animal is accidentally given too much insulin and begins convulsing. To quickly return the animal to a normal blood sugar you could
   A. provide sugar in a fruit drink
   B. increase water intake
   C. inject erythropoietin
   D. cool the animal as rapidly as possible

7. In times of stress, under the influence of cortisol, amino acid levels increase in the blood. Why is an increase in the amino acid level in the blood beneficial as a response to stress?
   A. The amino acids are converted into proteins, which are used to repair cells damaged by the stress.
   B. The amino acids are converted to glucose by the liver, raising blood sugar, thereby providing more energy to deal with stress.
   C. The amino acids are converted into proteins, which provide more energy to deal with stress.
   D. The amino acids are converted to glycogen by the liver, lowering blood sugar, which stimulates the release of insulin.

8. Hypersecretion of the thyroid gland would cause a
   A. tendency not to gain weight, warm peripheral body temperature, and high energy level
   B. tendency to gain weight, cold peripheral body temperature, and high energy level
   C. tendency not to gain weight, cold peripheral body temperature, and low energy level
   D. tendency to gain weight, warm peripheral body temperature, and low energy level

9. NR Humans respond to stress by secreting ACTH, which causes an increase in blood sugar levels. In your notebook, place the correct number from **Figure 1** above the appropriate step. (Record all four digits of your answer.)

____	____	____	____
Nerve message signals stress.	Gland secretes ACTH.	Target organ for ACTH.	Organ responds to increased blood sugar.

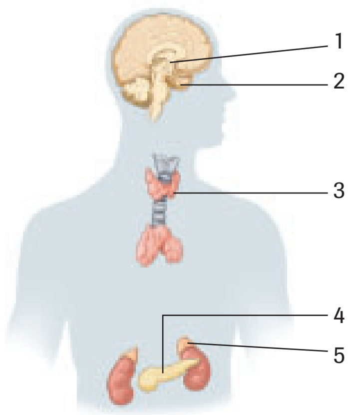

Figure 1

10. The thyroid disorder referred to as goiter is caused by
    A. low levels of TSH, which stimulate thyroid development
    B. low levels of thyroxine, which stimulate thyroid development
    C. decreased thyroxine due to decreased dietary iodine
    D. decreased TSH due to decreased dietary iodine

11. The body responds to a drop in blood pressure by
    A. increasing ADH production and water uptake, and decreasing urine formation
    B. decreasing ADH production and water uptake, and increasing urine formation
    C. increasing Na^+ and water reabsorption, and decreasing urine formation
    D. decreasing Na^+ and water reabsorption, and increasing urine formation

Part 2

12. **List** and **explain** the symptoms experienced by people with diabetes.
13. **Sketch** negative feedback diagrams to **illustrate** how insulin and glucagon regulate blood sugar.
14. With reference to the adrenal glands, **explain** how the nervous system and endocrine system interact in times of stress.
15. **Why** do insulin levels decrease during times of stress?
16. **Explain** the role osmoreceptors play in sensing the body's internal environment.
17. With reference to the importance of negative feedback, provide an example of **why** low levels of iodine in your diet can cause goiters.
18. DE A physician notes that individuals with a tumour on the pancreas secrete unusually high levels of insulin. Unfortunately, insulin in high concentrations causes blood sugar levels to fall below the normal acceptable range. In an attempt to correct the problem, the physician decides to inject the patient with cortisol. Write a unified response that addresses the following aspects of the cortisol treatment.
    - **Why** would the physician give the patient cortisol?
    - **Predict** the problems that might arise from this treatment.
19. A rare virus destroys cells of the anterior lobe of the pituitary. **Predict** how the destruction of the pituitary cells would affect blood sugar. **Explain**.
20. A physician notes that her patient is very active and remains warm on a cold day, even when wearing a light coat. Further discussion reveals that although the patient's daily food intake exceeds that of most people, the patient remains thin. **Why** might the doctor suspect a hormone imbalance? **Identify** which hormone the doctor might suspect.

Use the following information to answer questions 21 to 28.

Caffeine was one of the first performance-enhancing drugs used by athletes. Some people believe that it can increase endurance. Dramatic increases in caffeine levels and high consumption of caffeine have been linked with sleep disorders, impaired fine motor activities, increased fatty acid levels in the blood, and heart attacks. A study was conducted on a group of elite cyclists and a group of high school students to determine whether caffeine provided any marked advantage. Each group pedalled at 80 % maximum capacity for as long as possible. **Table 1** reveals the average amount of time each group was able to pedal after drinking decaffeinated coffee and drinking coffee with caffeine.

Table 1 Cycling Time and Caffeine Consumption in Two Groups

	Average cycling time (min)	
Group	***Decaffeinated coffee (250 mL)***	***Coffee with caffeine (250 mL, 340 mg caffeine)***
elite athletes	82	123
students	41	42

21. DE **Identify** the problem being investigated by the research group.
22. DE **Hypothesize** about the relationship between caffeine consumption and athletic endurance in non-athletes versus elite athletes.
23. DE **Identify** the control for the experiment.
24. DE **Identify** the independent and dependent variables.
25. DE **Infer** conclusions from the evidence in **Table 1**.
26. DE **Why** was neither group told which coffee contained caffeine?
27. DE The procedure does not indicate how much time passed between each exercise test. **Explain** why this is an important factor to know.
28. DE To learn more about how caffeine helps your body adjust to physical stress, you might want to monitor changes in certain hormones during testing. **Identify** hormone levels that you might want to monitor in the blood during the testing and explain what information might be gained by monitoring these hormones.

29. **Compare** the control system of a thermostat to the control system that regulates the body's blood sugar levels.
30. A survey by the Harvard School of Business indicated that CEOs are most often above average height. Another study commissioned by a women's magazine showed that men are attracted to taller women. **Describe** how studies such as these could lead to the misuse of recombinant growth hormone.

Unit 30 A REVIEW

Many of these questions are in the style of the Diploma Exam. You will find guidance for writing Diploma Exams in Appendix A5. Science Directing Words used in Diploma Exams are in bold type. Exam study tips and test-taking suggestions are on the Nelson Web site.

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Part 1

1. Use the data in **Table 1**, which compares plasma components (in g/100 mL of plasma) of several patients, and the key below to answer the following question.

Table 1 Plasma Components of Five Individuals

	Urea	Uric acid	Glucose	Amino acids	Proteins
normal person	0.03	0.004	0.10	0.05	8.00
patient 1	0.03	0.004	0.50	0.05	8.00
patient 2	0.03	0.005	1.70	0.05	8.00
patient 3	0.03	0.050	0.10	0.09	8.00
patient 4	0.07	0.004	0.10	0.06	4.00

According to the data provided, which patient(s) might have diabetes mellitus?
A. patient 1
B. patient 2
C. patient 3
D. patient 4

2. Sound is measured in decibels (dB). A normal conversation registers between 60 dB and 80 dB. Street traffic is about 80 dB and a rock concert can exceed 140 dB. Permanent damage occurs at 85 dB and pain is experienced at 120 dB. Hearing loss occurs when
A. ossicles of the middle ear pierce the tympanic membrane
B. violent wave-like motions cause fluids of the inner ear to tear the round window
C. vibrations tear hair cells from the basilar membrane of the cochlea
D. fluids build up in the Eustachian tube causing great pressure on the oval window

3. Identify the pathway in a simple reflex arc.
A. sensory receptor > sensory neuron > CNS > motor neuron
B. sensory neuron > interneuron > motor neuron > muscle or gland
C. interneuron > motor neuron > muscle or gland > motor receptor
D. motor receptor > sensory receptor > CNS > muscle or gland

Use the following information to answer questions 4 and 5.

During a football game, a receiver collides with a linebacker. Both football players collide and both appear to have received serious injuries. Both athletes are X-rayed upon arriving at the hospital. The linebacker is believed to have a fractured skull resulting in extensive damage to the motor cortex of the left frontal lobe of his brain. The receiver has no broken bones but lost feeling in his lower right leg. During the examination, the doctor uses a needle to gently poke the right leg of the receiver, beginning at the foot and working slowly upward on the leg. Further tests revealed that the loss of feeling in the receiver's leg is the result of a tear in the outer neural tissue at one location of the spinal cord.

4. By poking the receiver's leg with a needle, the physician is most likely
A. trying to locate the area of the leg where muscle damage occurred
B. trying to locate the area of the spinal cord where nerve damage occurred
C. trying to locate the area of the brain where nerve damage occurred
D. trying to locate the area of the leg where muscle and nerve damage occurred

5. Indicate what the prognosis for recovery for the linebacker would be if tests continued to yield memory loss and problems with motor coordination weeks after the initial check.
A. Good: grey matter of the brain has myelinated neurons, which have some capacity for repair.
B. Good: white matter of the brain has unmyelinated neurons, which have some capacity for repair.
C. Poor: grey matter of the brain has unmyelinated neurons, which have little capacity for repair.
D. Poor: white matter of the brain has myelinated neurons, which have little capacity for repair.

6. A fighter jet banks steeply to one side as it changes direction, i.e., one wing is lower than the other. In this situation, a pilot can sometimes become briefly disoriented, thinking that "down" is still toward his or her feet, even though the orientation of the aircraft has changed. How is the disorientation corrected?
A. The otoliths provide information on head position and the direction of gravity while the semicircular canals provide information on movement.
B. The cochlea provides information on head position and the direction of gravity while the semicircular canals provide information on movement.
C. The cochlea provides information on head position and the direction of gravity while the otoliths provide information on movement.
D. The otoliths provide information on head position and the direction of gravity while the cochlear canals provide information on movement.

Use **Figure 1** to answer questions 7 and 8.

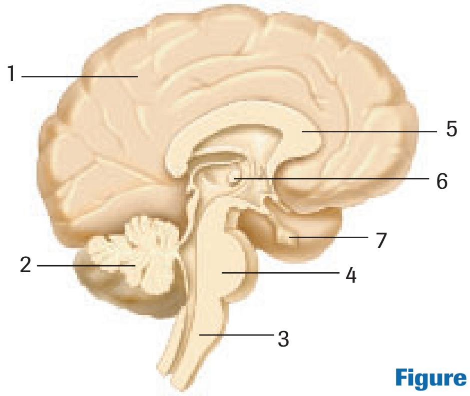

Figure 1

7. NR Identify the areas shown below by number. (Record all four digits of your answer.)

________	________	________	________
medulla oblongata	cerebellum	corpus callosum	pons

8. The function of the area labelled 5 is to

A. communicate between the right and left hemisphere
B. coordinate sensory and motor function from the cerebellum
C. store sensory information and sequence motor activity
D. coordinate the autonomic nervous system

9. NR Match each of the descriptions with the appropriate hormone. (Record all four digits of your answer.)

1. Released when blood Ca^{+} levels are low, this hormone causes the kidneys and gut to retain calcium while promoting calcium release from the bone.
2. Released into the blood during stressful situations, this pituitary hormone is carried to the adrenal glands where it stimulates the release of glucocorticoids.
3. Produced by the thyroid, this hormone increases metabolism and regulates growth.
4. Posterior pituitary hormone that acts upon the kidneys to increase water reabsorption.

________	________	________	________
ADH	thryoxine	PTH	ACTH

Part 2

10. **Illustrate** with a flow chart how the hypothalamus and ADH regulate the water content of blood.

11. **Outline** in a list the organs of the endocrine system.

12. In the homeostatic process of negative feedback, the secretion of most hormones is regulated by other hormones. Using thyroxine as an example, **sketch** a flow chart to **illustrate** this process of regulation by negative feedback.

13. A person's kidneys fail to respond to ADH. **Identify** the disease he or she suffers from and **describe** the physiological consequences of the disease.

14. **Compare** excitatory synapses to inhibitory synapses.

15. **Explain** why two stimuli, applied 0.0001 s apart, would produce only one nerve impulse along the fiber of a specific neuron.

16. Cerebral palsy is a group of disorders that affects body movement and muscle coordination. It is caused by damage to, or malformation of, the brain during development in the womb or in the first few years of life. The effects of cerebral palsy vary widely, from slight awkwardness of movement or hand control to eating difficulties, poor bladder and bowel control, and breathing problems. **Identify** which area(s) of the brain are most likely affected. **Explain** your answer.

17. **Describe** how the kidney senses changes in blood pressure and how it responds to those changes

18. **Describe** how the eye adjusts its focus when changing from looking at an object far away to looking at an object close by. Include the following terms in your description: point of focus, retina, ciliary muscle, suspensory ligaments, and lens.

19. DE **Explain** in a unified response how sounds are heard. In your explanation, include the following items:

- **Describe** the structures through which the sound waves and nerve impulses travel, beginning with the outer ear and ending with the cerebrum.
- **Describe** the function of each structure.

Use the following information to answer questions 20 to 22.

Prior to the work of Banting and Best, patients with type 1 diabetes mellitus usually died within months of the onset of the disease. Today, patients are treated with insulin injections; however, many of these patients do not escape insulin-related disorders brought on by the fluctuations in blood glucose levels. Changes in blood glucose may damage blood vessels, limiting circulation, which in turn can lead to blindness, kidney failure, and the destruction of muscle and nerve tissue in the hands and feet.

20. DE **Explain** why the transplant of islet cells from a donor's pancreas into a diabetic patient is a promising option.

21. DE **Describe** two technological challenges presented by islet transplants.

22. DE **Describe** one societal issue that researchers must face as islet transplants become more common.

Use the following information to answer questions 23 to 27.

On April 26, 1986, a nuclear accident in Chernobyl caused the release of radioactive wastes into the air. The extent of the problem is still unknown, but the effects on children have been the most extreme. One of the most dangerous radioactive materials released was iodine-131, which was absorbed by the thyroid glands of children. Iodine-131 causes inflammation of the thyroid gland and can lead to cancer.

23. DE **Describe** some possible symptoms of children who had their thyroid glands completely or partially destroyed.

24. DE **Sketch** a feedback loop that **illustrates** how thyroxine levels might be affected.

25. DE **Explain** why children were given non-radioactive iodine.

26. DE Initially, the government tried to suppress information about the nuclear accident. **Describe** what should have been done.

27. DE Nuclear wastes were carried over the European continent with weather. Should surrounding countries be able to demand financial and medical compensation? **Justify** your answer.

Use the following information to answer questions 28 to 32.

A laboratory experiment was conducted to determine the effect of thyroxine on metabolic rate. Four groups of adult male rats were used. All groups were maintained in similar environments, designed to provide maximum physical activity. Each group was provided with adequate supplies of water and one of the following diets:

Diet A: food containing all essential nutrients

Diet B: food containing all essential nutrients and an extract of thyroxine

Diet C: food containing all essential nutrients and a chemical that counteracts the effect of thyroxine

Diet D: food containing all essential nutrients, except iodine

The results of the experiment appear in **Table 3**.

Table 3 Metabolism of Four Rats Fed Different Diets

Group	Average initial mass (g)	Average mass after 2 weeks of treatment (g)	Final average oxygen consumption (mL/kg/min)
I (diet A)	310	312	4.0
II (diet ?)	320	309	10.1
III (diet ?)	318	340	2.7
IV (diet ?)	315	400	2.0

28. DE **Hypothesize** about the relationship between the variables (formulate a hypothesis) for this experiment.

29. DE **Identify** the dependent and independent variables.

30. DE Which group was most likely used as a control? **Explain** your response.

31. DE Diet B was most likely fed to which group(s)? **Explain** your answer.

32. DE Diet D was most likely fed to which group(s)? **Explain** your answer.

Use the following information to answer questions 33 to 36.

Serotonin is a naturally occurring neurotransmitter that has a role in determining mood and emotions. A shortage of serotonin has been linked to phobias, schizophrenia, aggressive behaviour, depression, uncontrolled appetite, and migraine headaches. Several types of drugs, shown in **Table 4**, affect serotonin levels.

Table 4 Effects of Various Drugs on Serotonin Levels

Drug	Effect
Prozac, Paxil, Zoloft	serotonin remains longer in the brain
clozapine	prevents serotonin from binding to the postsynaptic membranes
hallucinogens (LSD, ecstasy)	react directly with the serotonin receptors to produce the same effect as serotonin

33. DE **Why** is Prozac (fluoxetine hydrochloride) prescribed for people with depression?

34. DE **Identify** which drug should not be taken by someone experiencing clinical depression.

35. DE **Sketch** a diagram showing the effect of LSD or ecstasy on serotonin.

36. DE **Explain** how taking hallucinogens over time could reduce serotonin levels.

37. The formation of amyloid plaques in the brains of people with Alzheimer's disease can cause acetylcholine levels to drop. **Explain** how an acetylcholine deficiency could cause memory loss, a common symptom of Alzheimer's disease.

38. Review the focusing questions on page 402. Using the knowledge you have gained from this unit, briefly **outline** a response to each of these questions.